SCIENCE IN THE WORLD OF WORK

VOLUME I

APPLIED MECHANICS

In accordance with War Production Board regulations, this book is printed in a war-time economy format with reduced margins. However, the type page is standard for a book of this kind, and ease of reading is maintained.

At the end of the war when paper and binding materials are again plentiful, this book and other similar volumes will be reprinted in larger size with normal margins.

SCIENCE IN THE WORLD OF WORK

VOLUME I

APPLIED MECHANICS

BY

FRANK R. DEMING
Coordinator, State Trade School, Meriden, Conn.; Chairman Connecticut Curriculum Committee on Related Science

JOSEPH T. NERDEN
Head of the Department of Mathematics and Science, State Trade School, Meriden, Conn.; Connecticut Curriculum Committee on Related Science

WITH A FOREWORD BY

HERMAN S. HALL
State Supervisor, Trade and Industrial Education, Hartford, Conn

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON

THE MAPLE PRESS COMPANY, YORK, PA

PREFACE

"Science in the World of Work," developed originally to meet the demands of students in trade schools, embodies technique suitable also for use in high schools.

The book emphasizes the practical aspect of science by basing all experiments on real-life situations. The authors have employed the project or job method in their approach to the teaching of science, since they have found that the group method in general use in secondary schools makes an inadequate provision for the individual differences existing in any group of students.

The book in its present form represents the results of four years of classroom use. Much of the preliminary work in planning the course was done under the supervision of Dr. Charles R. Allen, then educational consultant of the Federal Board for Vocational Education. A state committee for Connecticut, organized by Herman S. Hall, State Supervisor of Trade and Industrial Education, worked with Dr. Allen in developing a practical related-science outline for trade schools.

"Science in the World of Work" presents a practical method of teaching science in that it incorporates individual effort through the project method and encourages individual thinking on a practical basis

through its *qualitative* presentation. This book is intended for the many science teachers whose greatest task is to make students think in terms of real-life situations rather than in terms of the standard forms found in any reference book.

Grateful acknowledgment is made by the authors to Mr. A. S. Boynton, State Director of Vocational Education, for valuable suggestions and encouragement and to Mr. L. A. Smith, Director of the Meriden State Trade School, for his cooperation. The authors are under special obligations to Mr. R. W. MacComiskey of the Connecticut State Trade School in Torrington for the subject matter contained in the block on "Sound." Acknowledgment is also made to the following State Trade School instructors who from their experience with preliminary forms of the text have made valuable criticisms and suggestions for its improvement: Robert E. Bateson, State Trade School, New Britain; Richard W. Howes, State Trade School, Bridgeport; Ernest Panciera, State Trade School, Manchester; Sylvester Deming, Boardman Trade School, New Haven; Frank A. Parker, State Trade School, Putnam; L. W. Eddy, State Trade School, Bridgeport; C. A. Gilbert, State Trade School, Stamford; and J. Clark, State Trade School, Bridgeport.

FRANK R. DEMING.
JOSEPH T. NERDEN.

MERIDEN, CONN.,
January, 1936.

CONTENTS

FOREWORD

The life situations involving scientific phenomena encountered by the average person or the skilled mechanic can be adequately met by a general qualitative understanding of the phenomena and the means for their control. Neither the average citizen nor the mechanic has occasion to measure or evaluate causes, effects, and reactions with mathematical scientific accuracy. Engineers and technicians employ accurate measurements and mathematical calculations in making science serve their needs. The professions use science in an exact quantitative way. The average person applies his knowledge of science only in a general qualitative way.

The ability to deal with scientific phenomena on a quantitative basis is more easily acquired when it follows a mastery of the qualitative concepts involved. Ability to work quantitatively with the concepts is a more advanced and difficult step and one that kills natural interest of many secondary school pupils.

It is very probable that secondary schools may well confine their instruction to qualitative understandings and applications. Certainly the first year of college preparatory work in science may be well spent in a thorough acquisition of purely qualitative concepts. For the non-college preparatory student, qualitative work alone will suffice.

The elimination of practically all quantitative science work will remove the necessity for using complicated instruments and expensive equipment and will avoid the distraction and loss of interest incident to a large amount of mathematical calculation. The qualitative concepts can be acquired by the use of simple articles and devices common to the everyday life of the student. The use of such equipment will insure the concepts of science being associated, in the minds of the students, with everyday life situations. This will inhibit any tendency on the part of the learner to think of scientific phenomena as something to be found only in the laboratory and which may be ignored in running the kitchen range, connecting up the Christmas-tree lights, operating the family car, and deciding if changes in the heating system are necessary.

The text provides for individual instruction and a tie-up of the concepts with life situations in a way that is pedagogically sound and administratively feasible. It is a valuable contribution to secondary education.

HERMAN S. HALL.
State Supervisor of Trade and Industrial Education

HARTFORD, CONN.,
January, 1936.

SCIENCE IN THE WORLD OF WORK

VOLUME I

BLOCK I

SIMPLE MACHINES

UNIT 1. Mechanical Advantage

If you were driving an automobile along a country road and were unfortunate enough to get stuck with a rear wheel in a rut, you would probably get out your jack and set to work raising the wheel high enough so that you could get some blocking under it.

Now why would you use your jack?

Wouldn't it be because you knew that you would be unable to lift the car without it?

The jack certainly wouldn't increase the strength of your muscles. Just exactly what would the jack do for you, if your own strength were the same whether you used the jack or tried to lift the car without it?

The following experiment is designed to help you answer this question.

EXPERIMENT

Put enough bricks in the box (Fig. 1) so that you cannot lift it. Now set a bar (a two by four, about ten feet long will do) over a horse as shown (Fig. 2) and adjust it so that

you can lift the loaded box off the floor by pushing down on the long end of the bar.

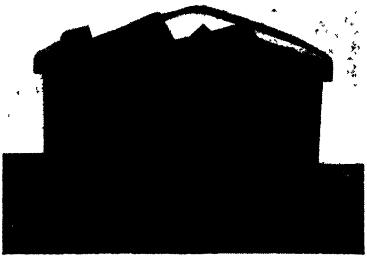


Fig. 1.

Try lifting the box, using different lengths of "bite."

Definition: A *bite* on a bar such as you are using is the distance from the horse to the load.

Note the difference in the amount of force that you have to use on the bar to lift the box of bricks, when the length of the bite is increased.

Note the difference in the amount of force required when the bite is decreased.

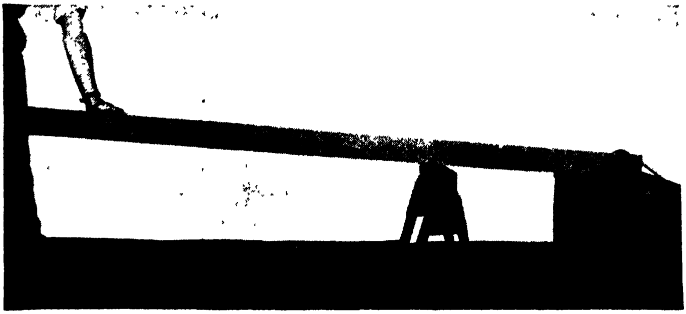


Fig. 2.

Also note the distance that your hands move up and down as compared with the distance that the loaded box moves,

when different lengths of bite are used. Record your observations in a data table similar to the one shown in Fig. 3. In filling in the table, use terms such as "very little," "more," "some," "less," "a great deal," "hardly any," etc. Remember that you are the force and the box is the weight.

DATA TABLE

Case No.	Length of bite	Force needed to lift box	Distance box moved through	Distance force moved through
1				
2				
3				
4				

FIG. 3.

Study the results in the data table carefully. Note especially what happened to the force needed to lift the box as the length of the bite was increased.

Write the answers to the following questions in your notebook, taking care that each answer makes a complete statement:

1. Would you say that you gained something by using a bar of this sort instead of lifting the load unaided by a mechanical device?

Definition: Whenever you can make effort easier by using a mechanical device you have a *mechanical advantage.*

2. Did the use of the bar in this experiment give you a mechanical advantage?

Ratchet lever-type hoist used for handling pipe lines in oil fields. Note the ease with which the workman lifts the heavy pipe. (*Construction Methods.*)

3. Did you find lifting easier when a short bite was used or when a longer bite was used?
4. What length of bite will give you the greater mechanical advantage, a short bite or a long bite?
5. If you were unable to lift the box the first time you tried it with the bar, what could you have done to the position of the horse to make it possible for you to lift the fully loaded box?
6. When the horse was in a position so as to give a great mechanical advantage, did your hands move through a greater or a less distance than the loaded box?
7. When the horse was in a position to give very little or no mechanical advantage, did your hands move through a greater or less distance than the box? Compare with your answer to Question 6.
8. From your answers to Questions 6 and 7, make a statement on how the distance that the load moves through varies with the mechanical advantage.
9. Can the mechanical advantage be estimated by observing and comparing the distances that the force and load move through?

Definition: The *pry* is the distance from the horse to your hands, measured along the bar.

10. If you had balanced the bar in the middle so that the bite and pry were equal, would you have been able to lift the box? Try this setup, if you have any doubt as to the answer.
11. If you had made the bite longer than the pry, could you have lifted the loaded box? Why? Try this setup, if you are in doubt.
12. Can you think of any instance where making the bite longer than the pry would be of any practical use? How about the old-fashioned well sweep as shown in Fig. 4?

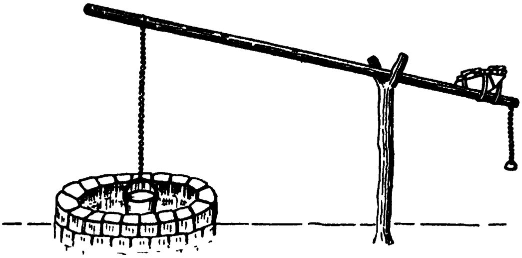


FIG. 4.

13. See if you can think of at least one other useful instance of a device where the bite is longer than the pry. Make a sketch and explain your case.

UNIT 2. The Lever

In the last experiment, you used a bar and a horse to raise a heavy load and discovered that such an arrangement could be made to produce a mechanical advantage. The arrangement is known as a lever.

Definition: A *lever* is a rigid bar that is capable of movement about a fixed support.

You also learned that the mechanical advantage could be varied by simply changing the position of the horse. In other words, with this lever, the longer you made the pry and the shorter you made the bite, the greater was the mechanical advantage. You also learned that, as the weight distance decreased and the force distance increased, the mechanical advantage

increased. In the experiments which you are about to do, the support will occupy a different position; it will be at the end of the bar, instead of between the load and force. You are to experiment with the apparatus to determine whether or not it is possible to get a mechanical advantage from setups of this sort, and, if so, how the mechanical advantage may be varied. You will try to discover for yourself what it is that determines the mechanical advantage of all types of levers. Levers of this sort are very frequently used in the trades. Practically every machine that has moving parts has the principle of a lever embodied in it. It is especially important, in your study of simple machines, that you learn to recognize these levers and the purposes that levers may serve.

EXPERIMENT A

For the first part of your experiment, set up your equipment as shown in Fig. 5. Put enough bricks in the box so

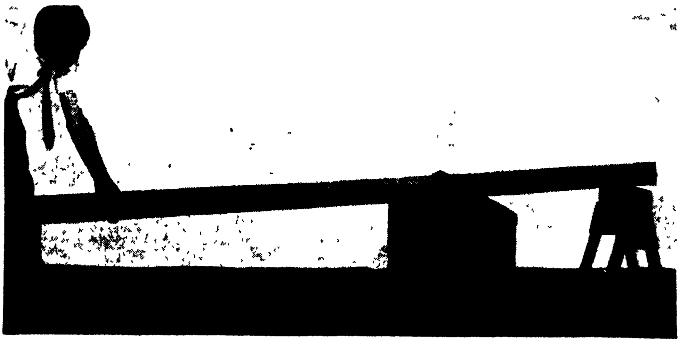


FIG. 5.

that you cannot lift it. Now, bearing in mind the definitions for *bite* and *pry*, try lifting the box, using different

lengths of bite, while applying your force at the end of the bar.

Try several different bites, as noted in the data table, and note the variation in the amount of force that you need to apply to the bar to lift the load. Also note the distances that your hands move up and down as compared with the distances that the loaded box moves in each position. Record your observations in a data table similar to the one following, using such terms as "most," "couldn't lift," "more," "very little," etc., to denote changes in the amount of force required. Also fill in the amounts of mechanical advantage that you obtained using terms such as "the most," "the least," etc.

DATA TABLE
Different Bites (Pry Remaining Same)

Case No.	Relation of pry to bite	Force needed to lift box	Distance box moved through	Distance force moved through	Amount of mechanical advantage
1	About 6 to 1				
2	About 4 to 1				
3	About 2 to 1				
4	Pry equal to bite				

FIG. 6.

Study the results shown in your data table. Note especially what happened to the force needed to lift the box as the length of the bite was changed. Remember, of course, that all other things remain the same.

Write the answers to the following questions on your paper, taking care that each answer makes a complete statement:

1. In which case did you obtain the most mechanical advantage?
2. In which case did the load move through the least distance? Is this the same case that resulted in the highest mechanical advantage?
3. Compare the results of your previous experiment with your latest results and tell whether or not the relation between pry and bite (pry greater than bite) still holds true in both cases of the lever, in order to obtain a mechanical advantage.
4. Tell also whether the results in both cases do or do not point to the fact that mechanical advantage may be obtained only when the distance that the force travels is greater than the distance that the weight travels.

EXPERIMENT B

For the second part of this experiment, try the setup as shown in Fig. 7. Put just a few bricks (about half a dozen) in the box and hook it on the end of the bar. Then

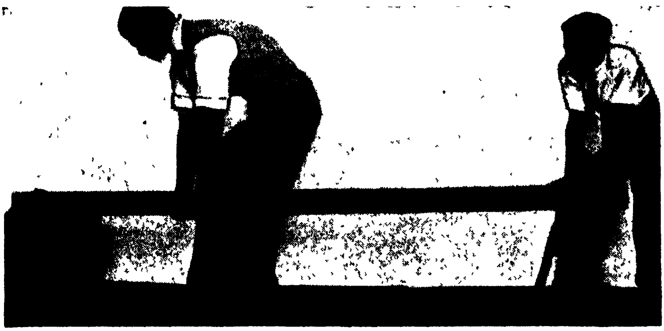


Fig. 7.

try lifting the box, using different lengths of pry, while allowing the box to remain at the end of the bar. Have another boy help you with your experiment by holding

down the loose end of the bar on the horse. Try four different lengths of pry, as noted in the data table, and follow the same procedure in experimenting and in filling out the data table as in the first part of the experiment. Following is the data table which you should use as your guide:

DATA TABLE
Different Prys (Bite Remaining Same)

Case No.	Relation of pry to bite	Force needed to lift box	Distance box moved through	Distance force moved through	Amount of mechanical advantage
1	About 1 to 6				
2	About 1 to 4				
3	About 1 to 2				
4	Pry equal to bite				

FIG. 8.

Study the results in the data table carefully. Note especially what happened to the force necessary to lift the box as the length of the pry was changed.

Write the answers to the following questions on your paper, taking care that each answer makes a complete statement:

5. In which case did you obtain a mechanical advantage?
6. How did the distance through which the weight moved compare with the distance through which the force moved?
7. Could you expect to get a mechanical advantage with such an arrangement?

General Conclusion: Does the experiment that you have just performed prove to you that, in order to obtain a

mechanical advantage in any lever, there must be a certain relation between the force distance and weight distance? If so, what should this relation be? Answer this question as your general conclusion.

ILLUSTRATIONS

One of the most common devices that show clearly how the principle of levers is applied to machines is the pliers. Figure 9 is a sketch of a pair of pliers showing the important points. Following is a sample problem in levers. Read it through carefully.

Sample Problem

Problem: Make a sketch of a pair of pliers showing the pry and bite, and explain what advantage is gained by its use.

Solution:

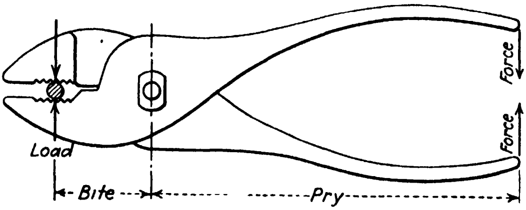


Fig. 9.

Since the bite is much shorter than the pry (about .5 to 1), one gets a large mechanical advantage (about 5 to 1) in using the pliers pictured in Fig. 9.

Not all levers are straight levers. In the above sketch, and in many examples that you will meet later, this will be evident. Many levers, in the form of handles, gear shifts, etc., are bent levers. In these

cases, the bite would be the perpendicular distance from the support to the line of motion of the load, while the pry would be the perpendicular distance from the support to the line of motion of the force.

Follow the same procedure as that shown in the sample problem, and explain the following illustrations:

8. Make a sketch of a wheelbarrow showing the bite and pry and explain what advantage if any is gained by its use.
9. Do the same for a pair of tin snips.
10. Do the same for a claw hammer as used to pull out a nail.
11. Do the same for a nutcracker cracking a nut.
12. Do the same for a pinch bar moving heavy load.
13. Make a sketch of your own forearm as it is used to throw a baseball, labeling the pry, bite, force, load, and support. Does it act like a lever? Which is longer, the pry or the bite? (If this question puzzles you, have your instructor explain to you the way that the muscles are attached to the forearm, and how the elbow acts as a hinge.)

SUMMARY

Copy the following statements on your own sheet and fill in the missing words:

14. In any lever, the mechanical advantage is always .... when the bite is shorter than the pry than when they are equal.
15. In order to obtain a mechanical advantage in any lever, the force distance must be .... than the weight distance.
16. When the bite is .. .. than the pry, there is no mechanical advantage in that lever.

17. If the distance through which the weight moves is .... than the distance through which the force moves, there is no mechanical advantage.

UNIT 3. The Wheel and Axle, or Windlass

Many of the old wells still found in rural districts use the wheel-and-axle method of raising water from the bottom of the well. It is a method that has been in use for centuries. The wheel and axle is also used for hoisting ore from mines, raising anchors on boats, for deck winches, etc. Figure 10 shows a windlass.

Note that the apparatus operates by a crank. This is the type commonly used for hand hoisting. When a wheel is substituted for the crank handle, the device is then called a wheel and axle. This is the type commonly used for continuous work, where a belt or chain, running on the wheel, operates constantly.

Now why do you suppose people use the wheel and axle, rather than do the work unaided by any mechanical device?

Do you suppose that you could do as much lifting with one wheel and axle as with another?

Can you think what it is that might make one wheel-and-axle device more powerful than another?

The following experiment is designed to help you answer these questions for yourself.

EXPERIMENT

The apparatus illustrated in Fig. 10 is a windlass. You will note that by turning the handle, and winding the rope on the axle, you are able to lift the box of bricks.

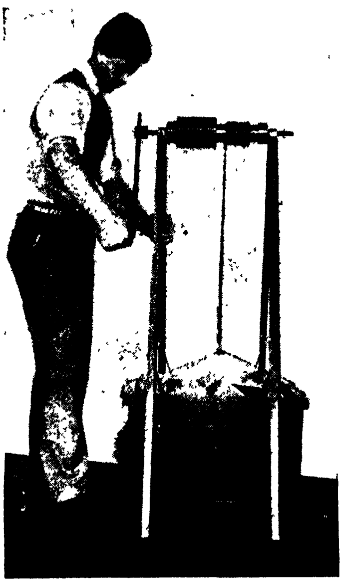


FIG. 10.

First, load the box full of bricks so that you cannot lift it by hand. Then with the rope on the small axle, and with the handle set at its greatest length, try to lift the box from the floor by turning the crank.

Write the answers to the following questions in your notebook, taking care that each answer makes a complete statement:

1. Are you able to lift the box, using a device of this sort?
2. Would you say, then, that by using a windlass you had an advantage over lifting without it?

General Conclusion: Make a statement telling whether or not you discovered that the windlass, or wheel and axle, has a mechanical advantage.

If you examine the apparatus, you will notice that for experimental use the crank handle is made adjustable by resetting the small screw in the hub, and that the size of the axle may also be changed by using the large section of the axle instead of the part that you have already used. You

must now investigate and see what happens to the advantage that you may receive from the windlass when the axle size is changed, or when the length of the crank handle is changed. Experiment with each item separately, and tabulate your observations as indicated in the following data table, using terms such as "a little," "more," "less," "the most," "the least," etc., to denote changes.

DATA TABLE
Change of Axle Diameter (Crank Remaining Same)

Case No.	Size of axle	Amount of force required	Distance that force moved	Distance that weight moved	Amount of mechanical advantage
1	Small				
2	Large				

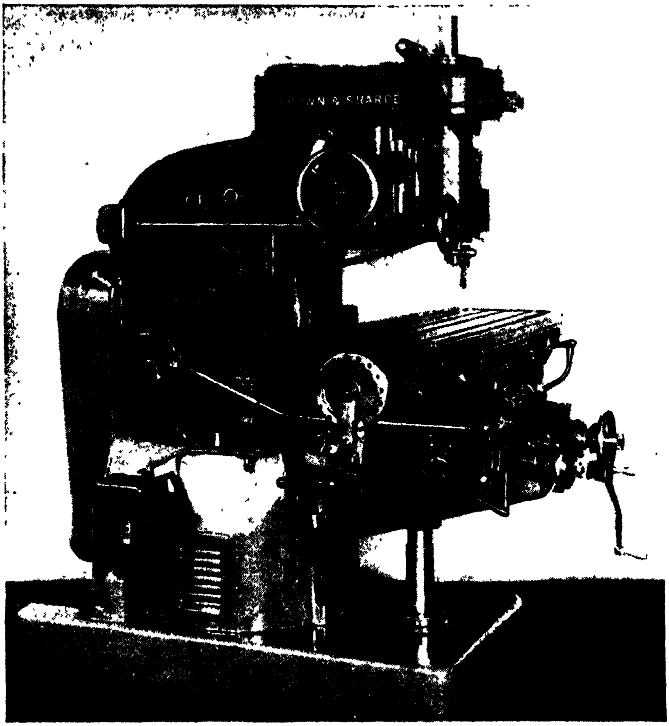
Fig. 11.

Examine the results shown in your data table carefully. Note, especially, what happened to the force needed to lift the box as the axle diameter increased.

3. Did you feel any difference in the amount of force needed to raise the box as the axle diameter was changed?
4. Would this indicate that the mechanical advantage was different for both cases?
5. Do you think that the diameter of the axle can be varied to control the amount of mechanical advantage that you may receive?

Definition: If you make a change in the setup or operation of an experiment without changing anything else, and if this single change always makes a difference in the results of your experiment, the change you made is called a *control factor*.

Control Factor: Can you call the axle diameter of a windlass a control factor of the mechanical advantage? If so, state it as Control Factor 1 on your paper.



Vertical-spindle milling machine. Note the extensive use made of the seven simple machines in its construction. (*Brown & Sharpe Manufacturing Company.*)

To determine whether or not the length of the crank handle may or may not be a control factor, allow the axle diameter to remain the same, while you change the length of the handle. Use the following data table as your guide.

Tabulate your results, using terms such as you used in previous data tables to denote changes.

Data Table
Change of Crank Length (Axle Remaining Same)

Case No.	Length of crank	Amount of force required	Distance that force moved	Distance that weight moved	Amount of mechanical advantage
1	Very long				
2	A little shorter				
3	Even shorter				
4	Very short				

Fig. 12.

Examine the results shown in your data table carefully. Note especially what happened to the force needed to lift the box when the length of the crank handle was varied.

6. Did you feel any difference in the amount of force needed to raise the box as the length of the crank was changed?
7. Would this indicate that the mechanical advantage was different for all cases?
8. Do you think that the crank handle can be varied to control the amount of mechanical advantage that you may receive?

Control Factor: Can you call the length of the crank a control factor? If so, state it as such on your paper, as Control Factor 2.

9. Now, referring to the results of the last two columns in both tables, in each case that you gained a mechanical advantage, was the force distance larger or smaller than the weight distance?
10. As the mechanical advantage increased, what happened to the distance through which the force had to travel?

11. As the mechanical advantage increased, what happened to the distance through which the weight had to move?

12. Is it a general rule that, in any simple machine that you have investigated so far, in order to produce greater mechanical advantage, the force distance must be increased or the weight distance must be decreased?

SUMMARY

13. The correct way to increase the mechanical advantage of a wheel and axle, and keep the axle size constant, is to . . . . . .

14. The factors that control the mechanical advantage of a wheel and axle are . . . . .

15. Increasing the axle diameter of a wheel and axle while allowing the crank to remain the same . . . the mechanical advantage.

UNIT 4. The Block and Tackle

Another one of the so-called simple machines that is commonly used for hoisting is the block and tackle.

Definition: The *block* is that piece of the apparatus which has one or more pulleys or sheaves, as shown by Fig. 13. When two of these blocks are hooked up together with the ropes through the pulleys, the arrangement is called a *block and tackle.*

The block and tackle has many uses in many different places. In shops, it is used for lifting heavy steel shafts, raising motors, moving machinery, and such tasks, while outside the shops the block and tackle is frequently used for jobs such as furniture moving,

raising and lowering painter's scaffolds, etc. On sailing ships the block and tackle is indispensable for such work as raising and lowering heavy sails and spars. These are just a few of the many uses for this simple machine. It will be your task in the following experiment to investigate the block and tackle and try to determine, first, whether or not it has a mechanical advantage, and, second, if there is a mechanical advantage, what are the control factors.

FIG. 13.

EXPERIMENT

Using the same wooden box as that used for the last experiment, fill it full of bricks, that is, enough bricks so that you cannot lift the box. Now, tie one end of the rope of a single fixed pulley hookup to the box, as shown in Fig. 14, and try to lift the box by pulling on the other end of the rope.

FIG. 14.

Repeat the procedure of trying to lift the box, using apparatus as shown in Figs. 15 to 20 inclusive. Note especially the amount of force that you had to apply to the rope in each case, and record your observations in a data table similar to the one shown in Fig. 21. Record also the distances through which the force and the weight moved. Use terms such as "very difficult," "harder,"

Fig. 15

Fig. 16

Fig. 17

Fig. 18.

Fig. 19.

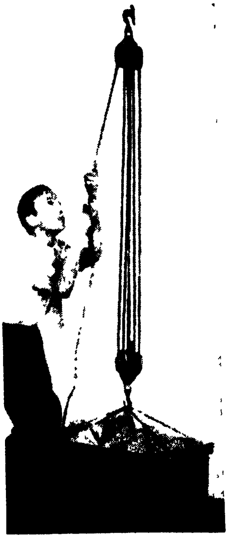


Fig. 20.

"easier," "couldn't lift," etc., in your data table to denote changes in the amount of force required, and similar terms to denote changes in the distances.

DATA TABLE

Case No.	Number of ropes on movable block	Force needed to lift the box	Distance weight moved through	Distance force moved through	Amount of mechanical advantage
1					
2					
3					
4					
5					
6					
7					

FIG. 21.

In order to fill the column labeled "Number of ropes on movable block," you must first know what a fixed block and a movable block are. The upper blocks in the tackles which you use are all fixed to a rigid beam and are, therefore, called fixed blocks. The lower blocks tend to move when force is applied to the rope and are therefore called movable blocks. The number of ropes leaving the movable block is the information which you should post in the specified column. For instance, in Fig. 18, there are four ropes leaving the movable block. The number 4 should be placed in the correct position in the specified column of the table.

Study the results in the data table carefully. Note especially the change in force and distance.

Write the answers to the following questions on your paper, taking care that each answer makes a complete statement:

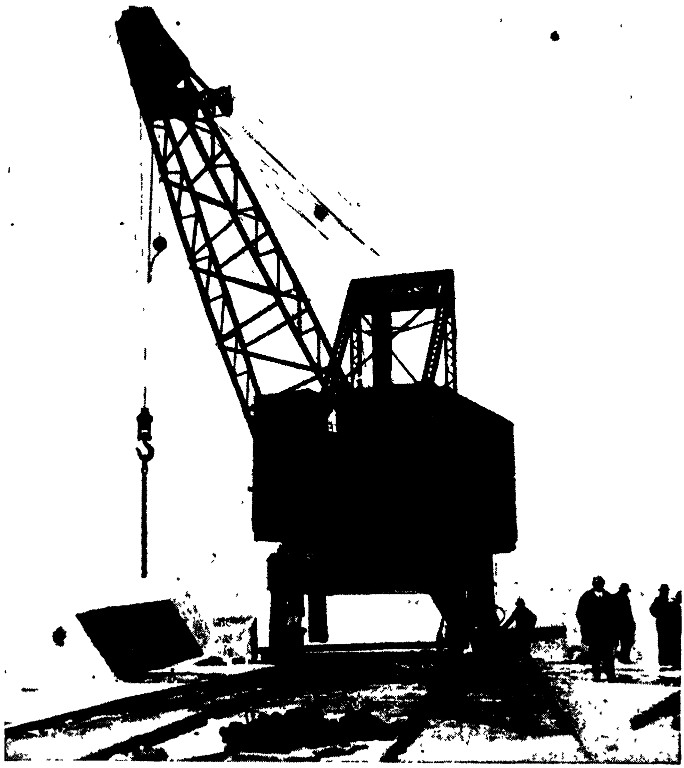
1. Would you say that you gained something by using the block and tackle to lift the loaded box instead of using your bare hands? Would this gain be a mechanical advantage?

General Conclusion: Make a statement telling whether your experiment demonstrated to you that the block and tackle did or did not give a mechanical advantage.

2. How did the force needed to lift the box change as the number of ropes acting on the movable block increased?
3. Since the number of ropes acting on the movable block was the only item that changed, while everything else remained the same, do you think that the mechanical advantage of the block and tackle may be controlled by these ropes?

Control Factors: Make a statement, now, on your paper telling what you have determined for control factors in your experiment on the block and tackle.

4. In the first case (Fig. 14), what distance did the box move through as compared with the distance that the force moved through?
5. Referring to your answer of the previous question, could you expect to get a mechanical advantage?
6. As the number of ropes acting on the movable block increased, what happened to the distance through which the box of bricks moved as compared with the distance through which your hands moved?
7. What happened to the corresponding mechanical advantage?
8. Make a statement now, telling whether or not you believe that the same rule of "decreasing the weight distance, or increasing the force distance, to gain a mechanical advantage" applies to the block and tackle in the same manner as it applied to the other simple machines that you studied in previous experiments.



Crane. Illustrates commercial use of the block and tackle. (*Construction Methods.*)

SUMMARY

Copy the following statements on your own paper and fill in the words which make the statements true:

9. Increasing the number of ropes acting on the movable block always .... the mechanical advantage of the block and tackle.
10. The load moves through .. . distance and gives . ... mechanical advantage when a pair of triple blocks are used than when a pair of single blocks are used.

11. In order to increase the mechanical advantage of a block and tackle, the distance through which the .... moves must be increased.
12. The weight may be raised more quickly but with . . ... mechanical advantage when a set of ... ... blocks is used in place of a pair of double blocks.
13. Referring to Fig. 15, it is easily seen that the weight distance is . ... than the force distance, and consequently it takes . . .. force to lift the box than when a setup such as is shown by Fig. 14 is used.

UNIT 5. The Differential Hoist

Perhaps you have seen in use somewhere the differential hoist, which you are to study in this unit. Most automobile repair shops and wrecking cars have a frame from which a differential chain hoist is hung for lifting engine blocks or wrecked cars. It is used in the machine shop and foundry for lifting heavy castings. In fact, anywhere that a strong steady pull is needed you will be apt to find a differential hoist in use.

Why is it that this particular type of lifting machine is so often used? Has it a mechanical advantage, and, if so, what are the factors that control it? You should be able to find the answers to these questions by doing the following experiment.

You will use the experimental apparatus for this experiment instead of a commercial chain hoist,

because you can change the pulleys in the experimental apparatus. (You should examine the commercial ¼-ton Yale and Towne chain hoist and satisfy yourself that the same principle is used in it.) This experimental differential pulley apparatus is composed of an upper frame holding two pulleys of different sizes, which are fastened together and move as one pulley, a lower movable pulley, and a continuous rope running over the pulleys as shown in Fig. 22.


Fig. 22.

EXPERIMENT

Put about half a dozen bricks in the box; then lift it to feel its weight. With the apparatus set up as shown in Fig. 22, and with a 12-in. and an 11-in. wheel in the upper frame, place the loaded box on the hoist hook. Now raise the load by pulling on the rope that runs directly off the large pulley. Note the amount of force that you had to exert to raise the box with the hoist. Note also the distance through which your hands moved as compared with the distance through which the loaded box moved. Record all your observations in a data table similar to the one shown in Fig. 23. Use terms such as "a little," "more," "the least," "the most," etc., to denote changes.

Now remove the 11-in.-diameter wheel from the upper frame and replace it with a 10-in.-diameter wheel. Try

lifting the box with this new arrangement. Then, repeat the same procedure by changing the 10-in.-diameter wheel for an 8-in.-diameter wheel. Try lifting the box again. Record all your observations.

DATA TABLE

Case No.	Wheel diameters, inches	Amount of force needed	Distance force moved through	Distance weight moved through	Amount of mechanical advantage
1	12 and 11				
2	12 and 10				
3	12 and 8				

FIG. 23.

Study the results in the data table. Then answer the following questions, taking care that each answer makes a complete statement:

1. Did you gain an advantage by lifting the box with the differential hoist, rather than with your bare hands? If so, would this advantage be called a mechanical advantage?

General Conclusion: Make a statement telling whether your experiment on the differential hoist proved to you that the hoist did or did not have a mechanical advantage.

2. Did the amount of force necessary to lift the loaded box vary at all as the small differential pulley was made smaller, while the large wheel remained constant?
3. If so, would this variation indicate that the mechanical advantage was being varied likewise?
4. Would the factor that caused the variation be a control factor? Why?

Control Factor: Make a statement telling whether or not the change in the difference of the diameters of the

two pulleys of any one differential hoist (the large pulley remaining constant) is a control factor.

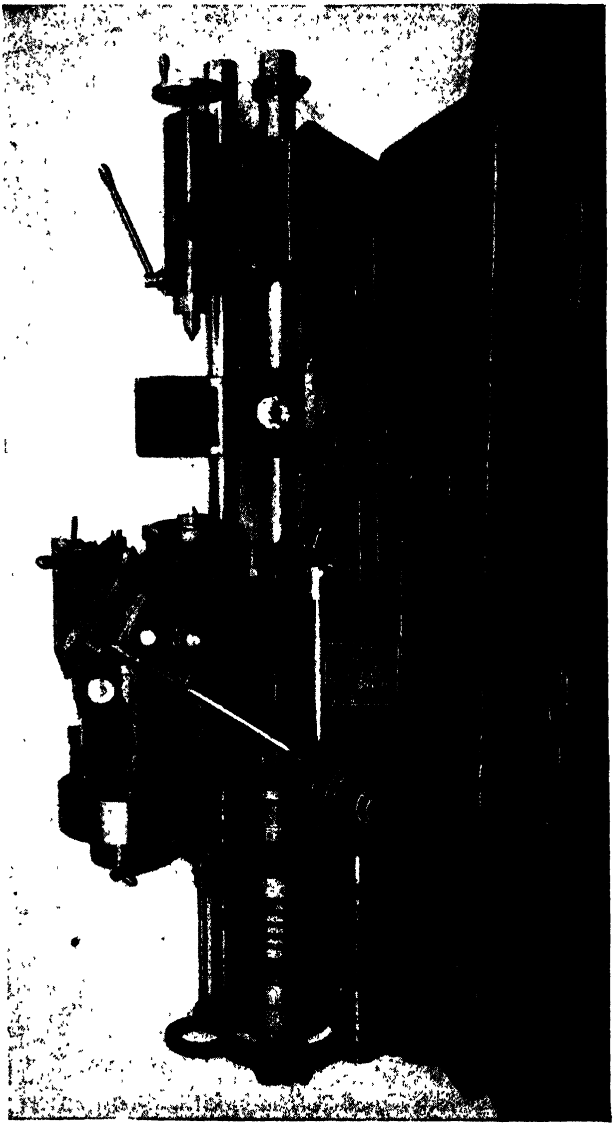
5. You might make other changes, one at a time, such as:
   a. Changing the diameter of the large pulley while keeping the small pulley diameter constant.
   b. Changing the length of the rope.
   c. Changing the size of the movable pulley near the load.

   Try to determine whether or not the items listed above are control factors. Experiment with the apparatus if you like, or, if the decisions are apparent to you, make your answers directly as complete statements.
6. Refer now to the two columns of your data table which contain the information about the force distance and the weight distance. As the mechanical advantage decreased, what happened to the distance through which your hands traveled?
7. As the mechanical advantage decreased, what happened to the distance through which the load moved?
8. Recall the rule that has been proved true so far in all the experiments on simple machines that you have done; namely, "If the distance that the force moves is very much greater than the distance that the weight moves, there is a large mechanical advantage." The mechanical advantage, therefore, depends upon the relative distances the force and the weight move. Make a statement telling whether or not this same rule applies to the differential hoist. If not, how would you change the rule to fit the present case?

SUMMARY

Copy the following statements on your own paper, and fill in the words which will make the statements true:

9. In any differential hoist, where the diameter of the large differential wheel is held constant, it is possible to . .



This automatic lathe illustrates how very useful the lever and the wheel and axle can prove to be in commercial machinery. (*Jones & Lamson Machine Company.*)

. . . . the mechanical advantage by reducing the diameter of the small wheel.

10. The following is a list of the factors which control the mechanical advantage of the differential hoist.

a. . . . .

b. . . . .

c. . , etc.

11. It always takes . . . . force to lift a load on any one differential hoist where the large pulley diameter is held constant, and when the two wheels are more nearly the same size, than when there is a big difference between them.

12. If, in examining two similar differential hoists, you found that your hand must move through less distance with the first than with the second, while raising the load the same distance in each case, you would promptly conclude that the second hoist had . . . . mechanical advantage than the first.

13. It is . . . . to change the mechanical advantage of a differential hoist by using a larger wheel in the lower frame near the load.

14. Can you explain why it is that a small commercial differential chain hoist can lift 1/4 ton while another chain hoist of similar construction and the same difference in wheel diameters, but with larger wheels, can lift 1 ton?

UNIT 6. The Inclined Plane

The inclined plane is so simple that you would hardly think of calling it a machine; still, it is a simple machine and you are to study it next. It is nothing

more than a plank, or any other flat rigid surface, with one end higher than the other. Figure 24 shows a man rolling a barrel up a plank into the rear end of a truck. This is perhaps the most common everyday use of the inclined plane and one you have doubtless seen very many times. The plank forms the inclined plane in this case.

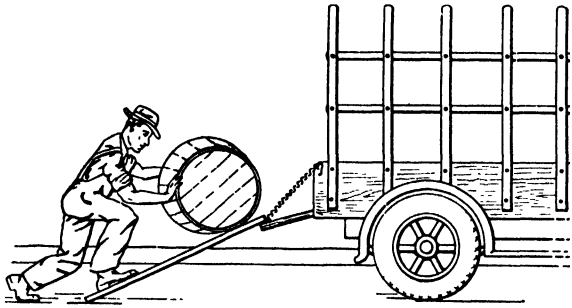


FIG. 24.

Do you think that it is easier to raise the barrel into the truck by using the inclined plane than to make a straight lift, without the use of a plank? How can you control the amount of advantage that you get, if any, by using the inclined plane?

Now see if you can answer these questions for yourself by doing the following experiment.

EXPERIMENT

Using the apparatus illustrated by Fig. 25, set the incline at a very small angle with the base. Put a heavy weight on the incline, and attach a piece of light rope or rawhide to it as shown.

Pull the weight up the incline, making certain that you pull parallel to the surface of the incline. Continue to slide the weight up the slope until it has reached the top. You have now raised the weight from the floor a distance equal to the height of the highest point of the incline. Note the amount of force that was necessary to raise the

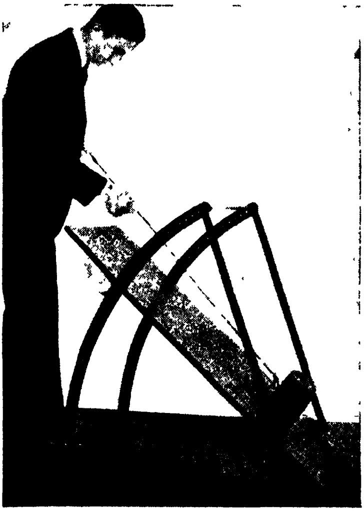


FIG. 25.

weight to this height. Also note the distance through which the force moved, and the vertical distance the weight moved. Now change the slope of the incline for a steeper pitch (about 30 deg.) and repeat the experiment. Try two more cases, making the slope steeper each time. Record all your observations in a data table similar to the one shown in Fig. 26. In filling in the table use terms such as "very little," "more," "some," "less," "the most," "the least," etc., to denote changes.

DATA TABLE

Case No.	Amount of slope	Distance force moved through	Vertical distance weight moved through	Amount of mechanical advantage
1				
2				
3				
4				

FIG. 26.

Study the results in the data table carefully. Note especially the amount of force necessary to raise the weight as the slope varied.

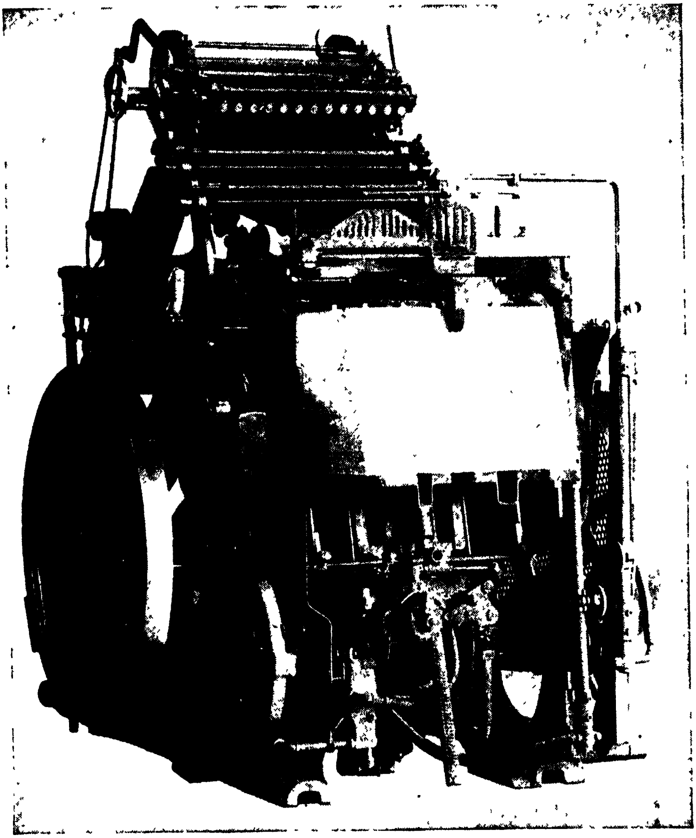
Write the answers to the following questions on your own paper, taking care that each answer makes a complete statement:

1. Have you proved that it is easier to slide a heavy weight up an inclined plane than it would be to raise it to an equal height by a straight lift?
2. Did you gain something by using an inclined plane?

General Conclusion: Make a statement telling what your investigation has proven to you about the inclined plane with regard to mechanical advantage.

3. As the incline was made steeper, did it take more force or less force to raise the load?
4. Would that indicate that the mechanical advantage was being varied too?

Control Factor: Since the slope was the only thing that was varied to produce a change in your results, can you call the slope a control factor of the mechanical advantage for an inclined plane? If so, state it as a control factor on your paper.



Job press with automatic feed. The printing press is actuated in many of its movements by cams, which in reality are nothing more than rotary wedges. Note the cam which operates the platen, and also the lever used to brake the speed of the press. (*Chandler & Price Company.*)

5. Are there any other items that might be considered as control factors? If so, list them. How about the width of the incline?

Refer now to the two columns which contain the information on the distances through which the force and the weight moved. Remember that the distance the weight moved is the vertical distance that it moved through, or, in other words, the height of the top of the incline above the floor level.

6. As the slope of the incline was increased, what happened to the vertical distance through which the load moved as compared with the distance through which your hands moved?
7. What happened to the corresponding mechanical advantage?
8. Make a statement now, telling whether or not you believe that the rule you made for all the other simple machines holds true for this case; namely, "Mechanical advantage of any machine depends upon the relative distances through which the force and weight move."

SUMMARY

Copy the following statements on your paper and fill in the words which make the statements true:

9. The greatest mechanical advantage was obtained on the inclined plane when the slope was . . . .
10. The mechanical advantage of an inclined plane may easily be varied by changing the . . . .
11. By decreasing the slope of the incline, and thereby . . . . the weight distance, the mechanical advantage may be . . . .
12. By increasing the angle of the incline from 20 deg. to 30 deg., the mechanical advantage may be . . . . and the vertical distance that the weight moves through may be

UNIT 7. The Wedge

The wedge is a very common example of the so-called simple machines. It is used oftentimes to lift the corners of buildings, to split logs, and to raise steamships off the keel blocks when ready for launching. A wedge is a tapered device, made of iron, wood, or some other strong material, and is driven by blows on its butt end. A wedge is really an inclined plane *moved under* a load, the load standing at rest as far as horizontal motion is concerned. In order to study the wedge and determine its control factors, several sets of wedges have been provided for your use.

EXPERIMENT

By studying Fig. 27, you may readily observe that pushing the wedges under the box of bricks will raise the box. The purpose of your experiment will be to determine whether or not, with such an arrangement, you obtain a mechanical advantage over direct lifting.

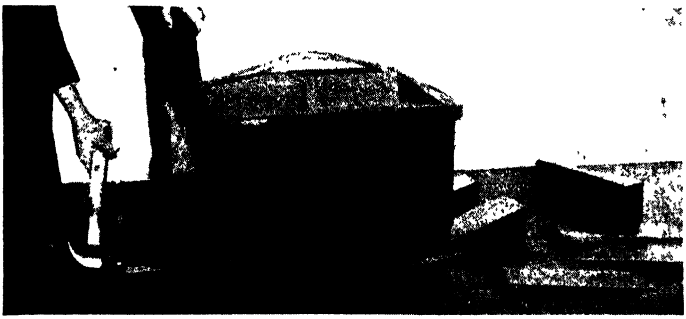


Fig. 27.

Load the box to the top with bricks to insure a heavy load. Select the set of four wedges whose slope is not very

great, and place one wedge under each corner of the box of bricks. Have the box just starting on the small ends of the wedges. Now, using a hammer or mallet, tap each wedge in turn with light blows until the box has been raised an inch or so off the floor. (It is important to note here that the manner in which the blow is delivered should not be considered as a vital point in this unit. The *one* idea to be emphasized is the fact that a series of equal forces is applied to each wedge.)

Try to strike the wedge with the same strength of blow each time. Note carefully the amount of force you have to apply to each wedge in order to raise the box, as compared with the amount of force that would be required to lift the box unaided through the same distance. Note also the distance through which the force moves, and the distance through which the load moves. (The distance that the force moves is the horizontal distance that each wedge slides along the floor, while the weight distance is the vertical distance that the box rises.) Record your observations in a data table similar to the one shown by Fig. 28, using the usual terms to denote changes.

DATA TABLE

Case No.	Amount of slope	Amount of force required	Vertical distance weight moved through	Distance force moved through	Amount of mechanical advantage
1					
2					
3					
4					

FIG. 28.

Repeat the experiment, using each of the other three sets of wedges individually. Note that the slope on each

successive set of wedges has been increased. Record all your observations in the same data table.

Study your data table carefully. Then answer the following questions taking care that each answer makes a complete statement:

1. Could you have lifted the loaded box easily unaided?
2. Was it easier to lift the box with the wedges than without them?
3. Did you obtain an advantage by using the wedges?

General Conclusion: Make a statement telling whether your investigation has proven to you that wedges are or are not capable of producing a mechanical advantage.

4. Did the box lift more easily with one set of wedges than with another?
5. Would that indicate that the mechanical advantage varied too? Why?

Control Factor: What was the one item that you changed in the procedure of your experiment each time? Was it a control factor? If so, state it as such on your paper.

6. Are there any other items that you consider as being control factors of the mechanical advantage of a wedge? If so, state them as such on your paper.
7. In which case did the weight move the least distance? Is this the same case as that in which the wedges had the greatest mechanical advantage?
8. In which case did the force move through the greatest distance? Is this the same case as that in which the wedges had the greatest mechanical advantage?
9. With special reference to your answers of the two previous questions, make a statement telling whether or not the rule that you made for all other simple machines still holds true and applies to the present case of the wedge;

namely, "The mechanical advantage depends on the relative distances that the force and weight move."

10. If the distance that the loaded box of bricks traveled vertically equalled the distance that the wedge slid horizontally, could you expect to receive a mechanical advantage? Why?

SUMMARY

Copy the following statements on your own paper, and fill in the words which make the statements true:

11. A wedge whose slope is not very steep will give ... mechanical advantage than another wedge whose slope is ....
12. Increasing the slope of a wedge .... the mechanical advantage.
13. If you were splitting a log with a wedge, and found that the wedge was not powerful enough to split the log, you would .... the slope of the wedge in order to .... its mechanical advantage.
14. By varying the .. .. of a wedge, it is possible to .... the mechanical advantage.

UNIT 8. The Screw

The last of the simple machines in this group is the screw. No doubt, you have seen it used in many different phases of your own shop work, for such tasks as operating a bench vise, raising an automobile axle with a jackscrew, bolting two pieces of material together, etc. One of the most common forms of the

screw is the jackscrew, the type that you are to use in your experiment, and from which you will try to find out whether or not the screw has a mechanical advantage, and, if so, what its control factors are. This jackscrew is shown by Fig. 29.

FIG. 29.

The illustration shows a jackscrew of the size that you commonly see used for heavy work, such as raising the corners of buildings. The jackscrew that you will use in your experiment is much smaller than the one shown in Fig. 29, but is sufficiently large to give the results of your experiment a very practical value. The principles involved in both the commercial and laboratory jack are identical. Figure 30 is an illustration of the several parts that are used in the experimental jackscrew. You

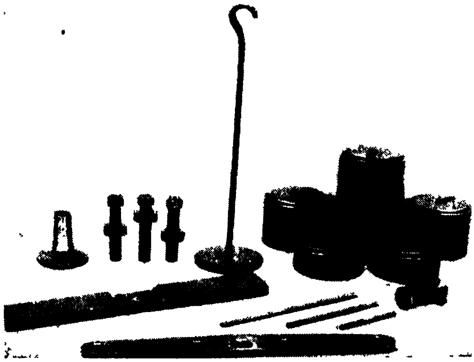


FIG. 30.

will note that only one of the weight hangers is shown, and only a few of the several weights used are shown.

EXPERIMENT

Set up the jackscrew as shown in Fig. 31. Set the base of the jack on the steel plate, and rest it on the two horses. Use any one of the screws that fit the base of the jack. Load each hanger with several large weights, that is, enough weight so that you have quite a heavy load on the jack. Make certain that the weight is evenly distributed among the four hangers.

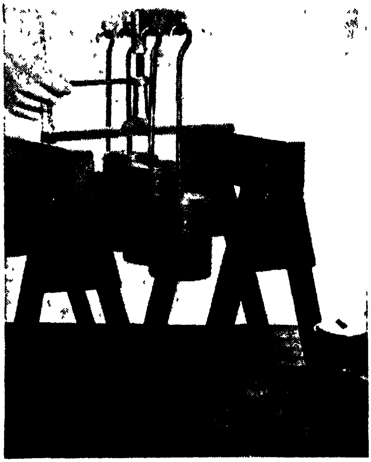


FIG. 31.

Now insert the long handle in the place provided for it in the nut, and apply enough force to the end of the handle to turn the screw, thereby raising the load.

1. Did the load raise easily?
2. Could you have lifted the same load as easily unaided by the jackscrew?

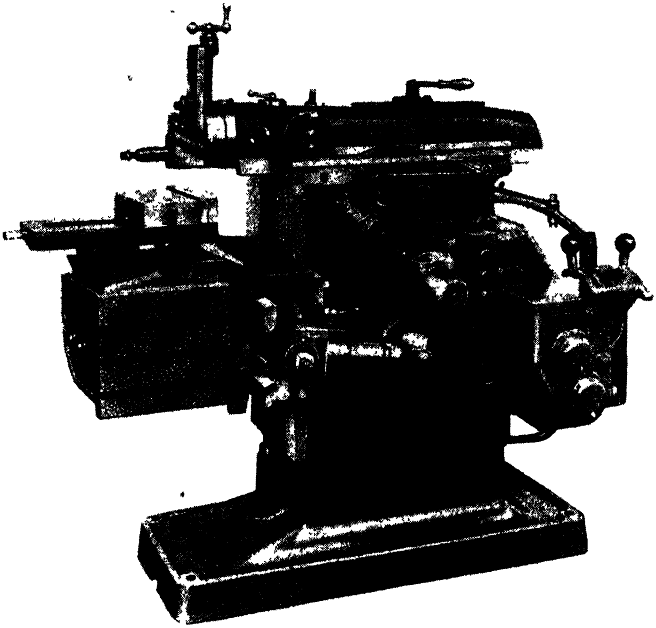
3. Would you say, then, that using the jackscrew gave you an advantage?

General Conclusion: Would this advantage be called a mechanical advantage? State your answer as the general conclusion.

In order to determine what the factors are that control the mechanical advantage of the jackscrew, several items should be considered: first, the effect that changing the lead of the screw has on the mechanical advantage, and, second, the effect that the length of the screw handle has on the mechanical advantage.

Definition: The *lead* of a screw (pronounced *lēd*) is the distance that the screw advances for one complete turn. In a single thread, the lead is equal to the pitch. The *pitch* is the distance from a point on one thread to the corresponding point on the next consecutive thread. Therefore, in screws that are double threaded, the lead is twice the pitch, and, in screws that are triple threaded, the lead is three times the pitch, because the screw advances double or triple the pitch distance in each respective case.

Set up the same jackscrew apparatus with the screw having the least lead, and, using the same handle throughout this part of the experiment, feel how much force it takes to raise the load. Repeat the experiment using two other screws having different leads. If you are not certain by the feel of the handle that your results are accurate, check yourself by attaching a spring scale to the end of the jack handle each time and compare the readings. Record all your observations in a data table similar to the one shown



Heavy-duty crank shaper. (*Hendey Machine Company.*)

by Fig. 32, making use of the usual terms to denote any changes that may occur.

DATA TABLE
Different Leads (Handle Remaining Same)

Case No.	Lead of the screw	Amount of force required	Distance load moved through	Distance force moved through	Amount of mechanical advantage
1					
2					
3					

FIG. 32.

Study the results in the data table carefully. Note especially what happened to the force necessary to raise the load as the lead of the screw was varied, and also note the relative distances that the force and the load moved for each case.

Write the answers to the following questions on your own paper, taking care that each answer makes a complete statement:

4. Did the amount of force necessary to lift the load change at all as the lead of the screw was varied?
5. Would this affect the mechanical advantage? Why?

Control Factor: Make a statement, now, telling whether your experiment has proven to you that the lead of the screw is or is not a control factor. If so, state your decision as the first control factor.

In determining whether the length of the handle has any effect on the mechanical advantage, you must set up the same jackscrew apparatus using, first, the longest handle available and any one of the three screws that you choose. Feel the amount of force that you have to apply to raise the load. Remembering that you must use the same screw and vary only the handle length, repeat the experiment using two other handles of different lengths. Record all your observations in a data table similar to the one shown by Fig. 33, making use of the usual terms to denote any changes that may occur.

Study the results in the data table carefully. Note especially what happened to the force necessary to raise the load, as the handle length was varied, and also note the relative distances that the force and the load moved for each case.

DATA TABLE

Different Handle Lengths (Lead Remaining Same)

Case No.	Length of the handle	Amount of force required	Distance load moved through	Distance force moved through	Amount of mechanical advantage
1					
2					
3					

FIG. 33.

Write the answers to the following questions on your own paper, taking care that each answer makes a complete statement:

6. Did the amount of force necessary to lift the load change at all as the length of the handle was varied?

7. Would this affect the mechanical advantage? Why?

Control Factor: Make a statement, now, telling whether your experiment has proven to you that the length of the handle used on a jackscrew is or is not a control factor. If so, state your decision as the second control factor.

8. What other items in the jackscrew can you think of that might control the mechanical advantage? Try out any that you think might be control factors, and list all your data in the usual manner.

9. Make a sketch of an inclined plane that coils upward. (Before making the sketch, cut a piece of paper in the shape of an inclined plane, and wind it around a pencil.)

10. Does the sketch that you drew look anything like a screw?

11. Would you say that the inclined plane and the screw were similar? Explain your answer fully in terms of your experiments on the inclined plane and screw.

SUMMARY

Copy the following statements on your paper, and fill in the word or words that make the statements true:

12. The screw with the .... lead will produce the most mechanical advantage.
13. The weight moves through the .... distance with the screw whose lead is the least.
14. The short handle produces .. .. .. mechanical advantage than a long handle when used in a jackscrew.
15. In order to gain the highest possible mechanical advantage, you should use a ... . handle in the jackscrew, and a screw whose lead is . . . ..
16. In screws that have a triple thread, you have to .... the pitch in order to find out how far the screw moves for one complete turn.
17. The pitch of a screw is ....
18. The lead of a screw is ....

UNIT 9. Illustrations of Simple Machines

The following questions and illustrations are based on the principles that you discovered in the foregoing experiments on simple machines. The questions are varied and will make it necessary to recall your notebook write-ups in some instances. Consider each case carefully; make a sketch of it, if possible, and explain your answer in detail and in such a manner that what you mean is unmistakable. Take care that each answer makes a complete statement.

1. If you were jacking up the rear axle of a very heavy truck and found that you could not raise the truck with the jack,

would a long piece of straight pipe with an inside diameter large enough to inclose the jack handle do you any good? Tell how you would use the pipe, and explain any additional mechanical advantage you might gain in terms of some control factor.

2. On a certain boat there was a deck winch. (A winch is one type of a wheel and axle.) As the rope came in over the side of the boat and wound itself around the hub of the winch, layer upon layer, it became increasingly difficult to raise the load. Explain why. Can you suggest some way in which this condition might be relieved somewhat?

3. Would you prefer to slide a heavy case, as shown in Fig. 34, up the steep incline or the shallow incline, if both rise to the same height? Which do you think would require more effort? Why?

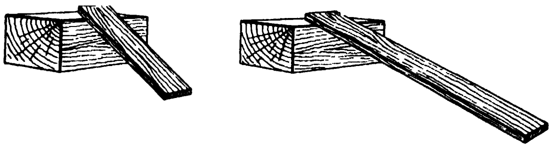


Fig. 34.

4. A bicycle has two sprockets over which the chain passes, one on the pedal wheel and the other on the rear wheel. On a bicycle that is being used mostly in very hilly country, is it advisable to have a sprocket on the rear wheel a little larger than normal, or a little smaller than normal? Explain your answer in detail, telling which experiment you are using as a basis for your claims.

5. Using the same length of handle, which vise would have the greater clamping effect, one having a lead screw finely threaded, or one coarsely threaded? Why?

6. Would reducing the size of an automobile's rear wheels, everything else remaining constant, make hill climbing easier or harder for the car? Why?

7. Which wedge would you judge, from Fig. 35, to be more powerful and useful in splitting the log? Why?

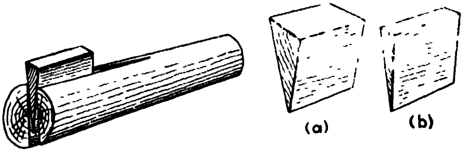


FIG. 35.

8. Could you use a wedge such as is shown by Fig. 35*a* to raise the supports of a building? Why?
9. If you were rigging up a windlass to hoist heavy boilers from the working floor of a plant to the shipping platform, would you make the difference between the radii of the handle and axle very small or very large? Why?
10. When using a nutcracker as in Fig. 36, in which position would you place the nut, near the hinge or near your hand? Why?

FIG. 36.

11. Examine Figs. 37 and 38. If you had to raise a load slightly more than your own weight, with a block and tackle, which setup would you use? Why?

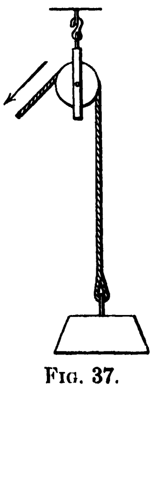


FIG. 37.

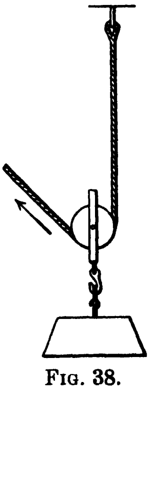


FIG. 38.

12. Figures 39 and 40 are illustrations of straight cams being pushed under followers that can travel only in a vertical direction. The followers operate a reciprocating device on an automatic machine. Which of the two cams should be used to give the reciprocating device more force? Why?

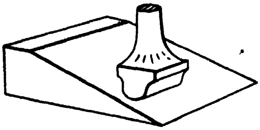


FIG. 39.

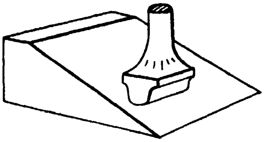


FIG. 40.

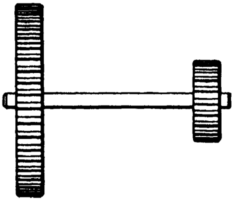


FIG. 41.

13. Two gears are keyed to the same shaft as shown in Fig. 41. A force is applied to the rim of the large gear. Will a tooth on the rim of the small gear exert more or less force than is exerted by one on the large gear? Why? Is there a mechanical advantage in such an arrangement?

14. A double-threaded jackscrew having a pitch of 1/4 in. is used to replace a single-threaded jackscrew whose pitch is 1/2 in. What is the difference between the mechanical advantages of the two jackscrews? Explain your answer.

15. A set of 1-in. anchor bolts is used to fasten a generator to a concrete foundation. If you were turning the nuts on with a 12-in. monkey wrench, and you had them as tight as you were able to get them, then discovered that they still were not tight enough to stop vibration in the generator when running, tell what measures you would take to give the nuts the extra turn which would stop the vibration. To what control factor of what experiment does your answer tie up?

16. Figure 42 shows a plan view of a binding device on a milling fixture. The clamp is movable about a bolt which is

screwed into the flat plate beneath it. If you wished to obtain the greatest possible mechanical advantage from the fixture, would you place the bolt at *a* or at *b*? Why?

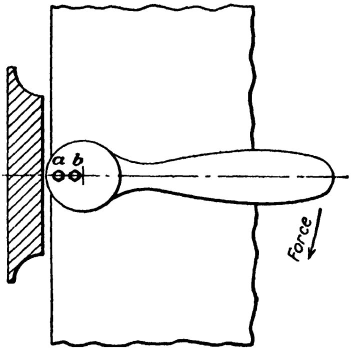


FIG. 42.

17. Two circular plate cams, used for holding a wire cable from slipping, as shown by Figs. 43 and 44, have all dimensions the same except as noted. Study these diagrams and state which cam will give the greater gripping power on the cable. Why?

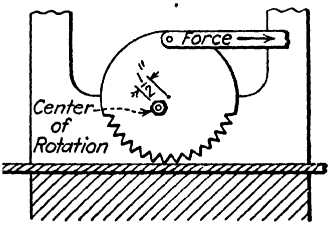


FIG. 43.

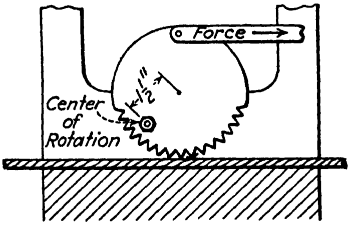


FIG. 44.

18. Two pulleys, a large one and small one, are keyed to the same shaft. The large pulley receives its power from a belt that is coming from an electric motor. The small pulley is delivering power, by means of a second belt, to a lathe. Draw a sketch of this pair of pulleys and show on it the dimensions that determine the mechanical advan-

tage. Does the setup have all the elements of some one simple machine? Which one? Explain each statement that you make fully.

19. Make a sketch or otherwise show that a wheel and axle is just a special case of the lever principle. (Your instructor will give you a hint if you need help.)

20. Figure 45 is a sketch of a setup of two double-pulley blocks that were used in an attempt to pull the rear wheels of a truck out of a mud hole. The attempt failed by a very little, just a little more pull was needed to do the job. Can you show any other arrangement of two double blocks that would give the additional pull? Explain in terms of some proved control factor just how you would gain by your setup.

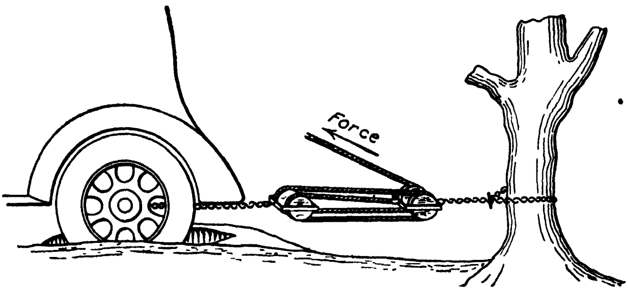


FIG. 45.

21. The bottom pulley on the differential hoist moves and has two strands of rope leaving it. (If you wish to check this statement, examine the apparatus yourself.) Look back in your notes under "Block and Tackle," and see what you wrote down as the control factor of the mechanical advantage of that simple machine. Now answer the following questions. Does the bottom movable pulley on the differential have an effect on the mechanical advantage of the machine? If so, how much?

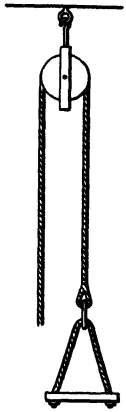


FIG. 46.

22. *a.* Suppose you sat in the saddle shown in Fig. 46 and tried lifting your own weight by pulling on the free end of the rope, would there be any mechanical advantage?

b. Suppose another boy, standing on the floor, pulled on the rope and lifted you, how hard would he have to pull as compared with the pull you made?

c. Was there a mechanical advantage in either case? If so, account for it in terms of some known control factor. (Try this setup and make sure that your answers are the right ones.)

23. Two roads, one coming from the south and the other from the north side of a mountain lead to the summit. The road from the south starts to incline at exactly 5 miles from the summit and continues in a direct line. The road from the north side also begins to incline at exactly 5 miles from the summit, but instead of making a direct ascent, it loops around the mountain before reaching the summit. If two men of like strength started up these inclines on foot, one on the north road and the other on the south road, which man would find the traveling much easier? Explain your answer in terms of weight and force distance. Which simple machine is illustrated here?

24. If you were buying a $\frac{1}{4}$ ton chain hoist for work in your own shop, and wanted to get a hoist with a mechanical advantage as great as possible, would you buy a hoist whose two differential wheels numbered 12 and 11 pockets, or 12 and 10 pockets? Why? Explain in detail.

25. Figure 47 shows the heavy fly-wheel and the reciprocating part of a punch press. Assuming that the force is caused entirely by the weight of the flywheel at the rim, explain whether you would connect the rod from the reciprocating part to the flywheel at *a* or at *b* in order to gain the better mechanical advantage. Explain fully in

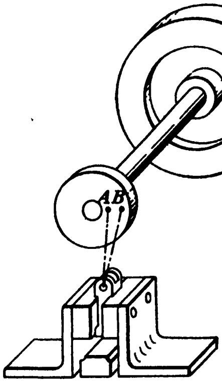


FIG. 47.

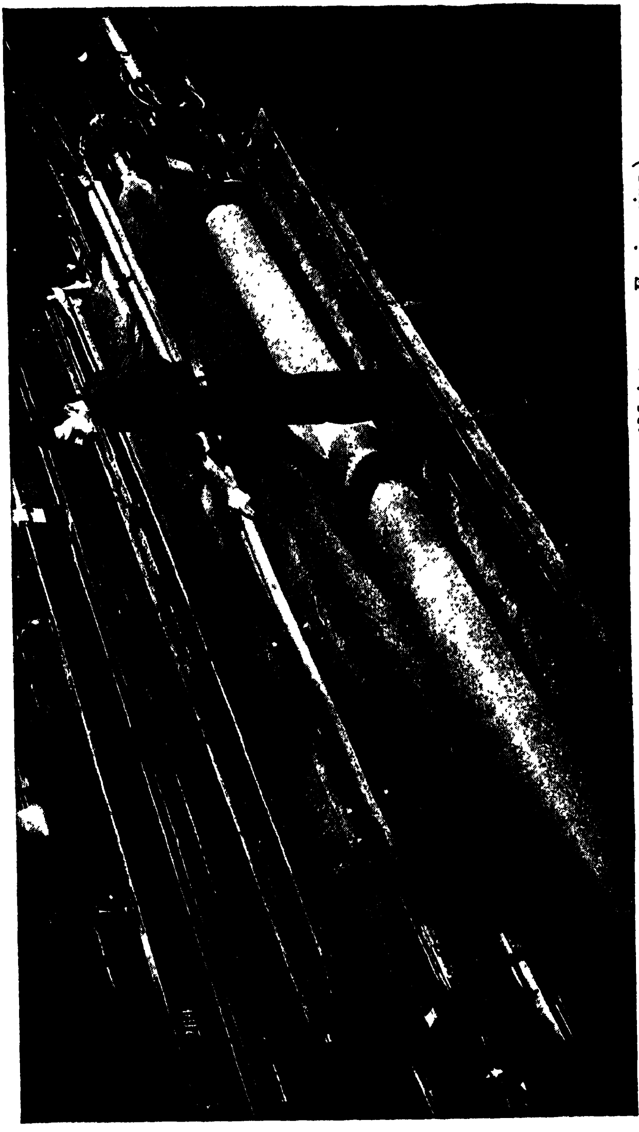
terms of weight distance and force distance. (NOTE: The flywheel rotates about its own center.)

26. Find at least ten more illustrations of the simple machines that you studied in the previous experiments, and explain each in detail. Make a free-hand sketch of each case, and in discussing the illustration on your paper, show clearly how the principle of some simple machine applies to it and discuss the force and weight distances of the illustration in detail.

UNIT 10. Compound Machines

You have now studied the simple machines and have demonstrated to your own satisfaction, many times, that they are useful devices for gaining force or distance as the case may be. You can now recognize any of the simple machines, no matter how much it may be disguised, as a working part of some commercial machine or equipment.

Perhaps you have already noticed from your observations of commercial machines used in your own shop that two or more of the simple machines are sometimes used in combination with each other to gain single effects of force or distance. This



One of the giant looms that weave Wilton rugs. *(Maintenance Engineering.)*

practice of combining several simple machines is very common, not only in machines found in your shop, but also in household appliances, farm machinery, and elsewhere. These combinations may be an assembly of a screw and a wheel and axle, as in an automobile steering mechanism; or they may be a screw and a wedge, or a pair of wedges, or any number of other combinations. Such complicated machinery as automatic screw machines may have very many separate applications of the simple machines working together to obtain some desired result. But how do we measure their usefulness?

Is it as easy to estimate the force gained, or the distance gained, in a combination of simple machines as in a single machine? Do you simply compare the distances through which the weight and force move to get the mechanical advantage? These are the things that you will determine in your experiment.

Definition: A combination of two or more simple machines which work together to produce one effect, is called a *compound machine.*

In the following experiment you will investigate several compound machines, determine the mechanical advantage, if any, and recognize and list the control factors in each case.

EXPERIMENT A

Figure 47*A* shows a piece of apparatus that you used in one of your former experiments, with the exception that it is now arranged in a different manner for the tests which

you are to make. Note that an endless rope is used. In order to set up the apparatus, you must remove the axle and drum from the standard upon which it is mounted and wind enough turns of rope on the drum and axle to bring the pulley hanging below to the necessary height above the base of the apparatus. Fill the regular box full of bricks and hook it to the pulley. Now, with the crank set at full length, try to raise the box.

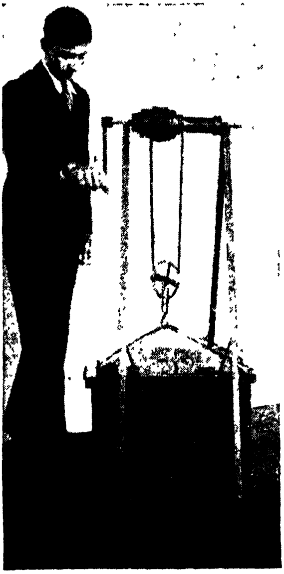


FIG. 47A.

1. Does the box lift more easily with the machine than without it?
2. Has the machine a mechanical advantage?
3. How does the mechanical advantage (if any) compare with the amount you could have obtained with either machine used separately?

Note carefully the distance through which your hand moves, when moved through an arc of about 45 deg., for it represents the force distance. Compare with this the dis-

DATA TABLE

Case No.	Combination of	Distance through which force moved	Distance through which weight moved	Amount of mechanical advantage
1				
2				
3				

FIG. 48.

tance through which the box moves, because this represents the weight distance. Record your observations in a data table similar to the one shown by Fig. 48, making use of the usual terms, "the most," "the least," "more," "less," etc.

Study Case 1 in the data table carefully. Then answer the following questions, taking care that each answer makes a complete statement:

4. What combination of simple machines is represented by the apparatus that you tested?
5. How does the force distance compare with the weight distance?
6. Would this indicate that you may obtain a mechanical advantage with the device?
7. Does your answer to the previous question agree with your answer to Question 2?

General Conclusion: You learned that in any one simple machine the mechanical advantage could be estimated by a comparison of the force distance and the weight distance. Make a statment here telling whether or not you believe that by the same method of comparison it is possible to determine whether a combination of several simple machines has a mechanical advantage.

Control Factors: Your previous study of the simple machines, plus a thorough examination of the apparatus, should enable you to determine what the factors are that control the mechanical advantage of the apparatus. Make a list on your paper of the control factors of the device.

EXPERIMENT B

Figure 49 shows a board on which a device made up of several strips of thin wood serves to illustrate a crude automobile braking system.

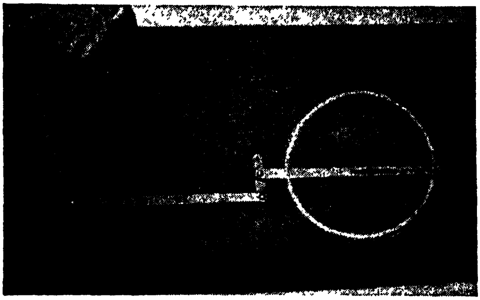


FIG. 49.

Examine the apparatus carefully. Now place your hand on the pedal of the device and move it through an angle of about 45 deg. Note carefully the distance through which your hand moves. Compare with this the distance through which the weight moves (the distance that the brake-band part of the apparatus moves). Record your observations in the data table.

Then answer the following questions:

8. What combination of simple machines is represented by the automobile braking apparatus?

9. How does the force distance compare with the weight distance?

10. Does this indicate that it is possible to obtain a mechanical advantage in an automobile braking system?

11. If the distance through which the pedal moves had been the same as the distance through which the brake moves, about how much mechanical advantage might you have expected to receive from the apparatus?

Control Factors: Examine the apparatus carefully, and make a list of the factors that control the mechanical advantage of the device.

12. *a.* Not all simple machines have a mechanical advantage. Likewise, in combinations of simple machines, not all

the simple machines which make up the compound machine have a mechanical advantage. Now, by observing the distance that the force and the weight end of each simple machine moves, tell which of the simple machines in the braking apparatus have a mechanical advantage.

b. Which machine or machines have no mechanical advantage in the combination?

EXPERIMENT C

The piece of apparatus shown in Fig. 50 is that of a hoisting crane. This apparatus is made up of a two by four hinged to the base of the windlass, a small rope pulley at the end of the boom, and a set of tackle blocks. It is operated by rotating the crank handle and thereby raising the loaded box, which is hooked, from the floor, to one of the tackle blocks.

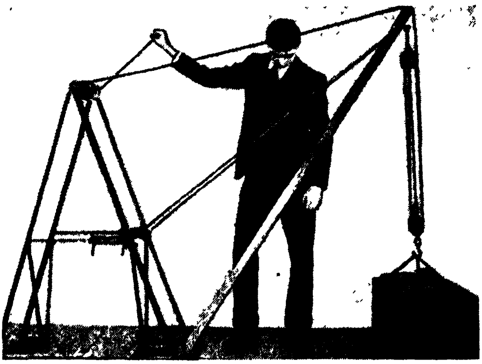


FIG. 50.

With the crank handle set at a convenient length, raise the box of bricks. Note carefully the distance through which your hand travels, when moved through an arc of about 45 deg. Compare with this the distance through

which the load moves. Record your observations in the data table.

Then answer the following questions.

13. What combination of simple machines is represented by the hoisting crane?
14. How does the force distance compare with the weight distance?
15. Does this indicate that you may obtain a mechanical advantage by using the crane?
16. Does the answer to the previous question agree with the facts recorded in your data table?

Control Factor: Examine the apparatus carefully, and make a list of the factors that control the mechanical advantage of the device.

17. Would it increase the mechanical advantage of the crane, if the length of the boom were increased? Explain.
18. Would it affect the mechanical advantage at all, if the rope leading directly to the windlass drum came out of the upper tackle block instead of the lower block? Explain your answer.

SUMMARY

Copy the following statements on your own paper, and fill in the missing words:

19. In all compound machines, as in all simple machines, if the distance through which the .... moves is greater than the distance through which the ..... . moves, the apparatus has a mechanical advantage.
20. It is possible to change the mechanical advantage of any simple or compound machine by changing just one . . .
. . . . . .

UNIT 11. Illustrations of Compound Machines

The following illustrations have been gathered at random from everyday life, without regard to any specific trade or industry. They should serve to bring out definitely the principles involved in compound machines, and also serve as a review of the simple machines.

In answering each question or problem, make your answer in the form of a full statement. Do not abbreviate or cut short your explanations. Make a sketch on your own paper of each compound machine, and label the parts where the force and load act with the letters *F* and *L*.

1. *a.* Figure 51 illustrates two gears running together and turning the lead screw of a lathe. This is a combination of which two simple machines?
   b. How would you go about getting a more powerful pull on the carriage, and still keep the revolutions per minute of the large gear the same?
   c. Can the mechanical advantage of the combination be changed by changing either of the two gears?

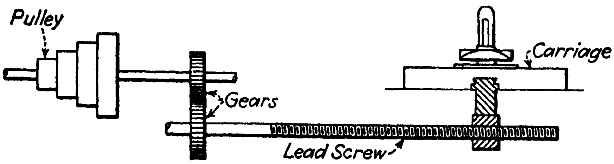


FIG. 51.

2. *a.* Figure 52 illustrates the steering mechanism of an automobile. Turning the wheel rotates the gear, which in turn rotates a shaft upon which a link is tightly fastened. The link moves pendulum fashion and operates the curved steel bar, which is connected directly to the front wheel. Explain which simple machines are represented by this combination.

b. Would a smaller handwheel make steering easier? Prove your answer by some principle that you have learned.

c. Has the size of the steering-wheel post any affect on the mechanical advantage? Explain your answer.

d. Has the diameter of the worm on the lower end of the steering post any effect on the mechanical advantage, if the lead of the worm remains constant?

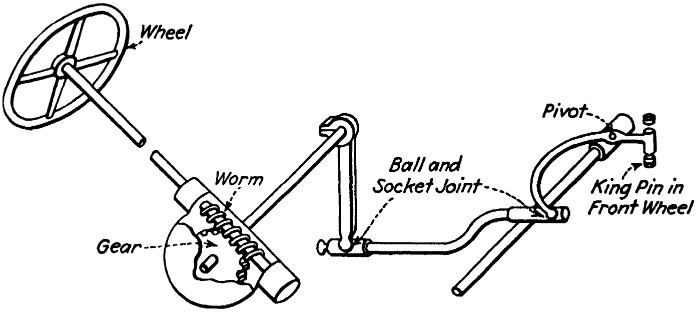


FIG. 52.

3. *a.* From the sketch of the automobile jack shown by Fig. 53, tell which simple machines are being used.

b. Would decreasing the lead of the screw affect the ease with which the jack lifts a car? Explain.

c. Make a list of all the factors, each of which you could change without changing any of the others, and thereby increase the mechanical advantage.

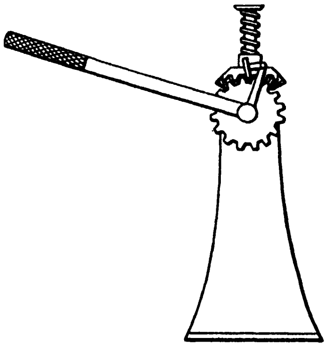


FIG. 53.

4. *a.* Simple machines are sometimes employed to give intermittent motion to a punch, as shown by Fig. 54. The

pulley on the left turns about its own center and operates by means of a connecting link and a bar whose center of rotation is fixed. The bar operates the reciprocating part through a ball-and-socket joint. From the sketch, tell which of the simple machines are used in the machine.

b. How could it affect the ease with which the punch operates, if the pin on the link running on the flywheel were moved closer to the flywheel center?

c. If you changed the apparatus now, so as to give the punch double the stroke that it originally had, would you expect the punch to increase or decrease its mechanical advantage? Explain your answer.

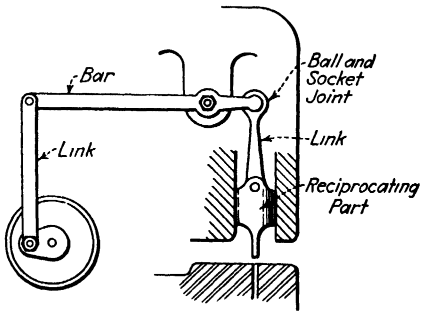


FIG. 54.

5. *a.* Figure 55 is a diagram of the working part of a small press. Note that by moving the handle, the small gear rotates and moves the ram. Examine the sketch and tell which of the simple machines are being represented.

b. If a wheel having a radius equal to the length of the handle were substituted for the handle, would the mechanical advantage be affected? If so, how?

c. Would it affect the mechanical advantage of the press, if the gear were made larger? If so, how?

d. If, in examining the press, you discovered that your hand traveled twenty times as far as the ram, about what force would you expect the ram to exert, in pressing

out an arbor, if you applied 50 lb. to the handle? (Neglect friction.)

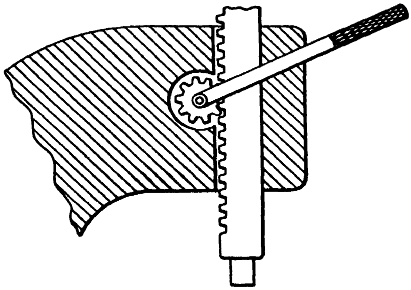


FIG. 55.

6. *a*. Figure 56 shows a machine used in metal trades for shearing off plate and bar stock. Note that the machine is operated by applying force to the end of the handle. Examine the sketch and tell which simple machines are used?

   b. Would it make any difference in the amount of force that you would have to apply to the handle if the bar of steel being cut were placed under the outer end of the blade? Explain your answer.

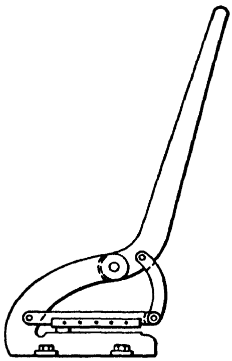


FIG. 56.

7. The device shown in Fig. 57 is that which is used in operating the valves on many kinds of automobiles. The rotating cam shaft is the means employed here to open and close the valves. From the sketch, tell which simple machines are being used.

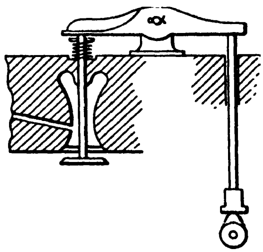


FIG. 57.

8. *a.* What simple machines are represented in a regular chain-and-sprocket bicycle?
   b. How would it affect the mechanical advantage of the bicycle if the sprocket on the rear wheel were increased in size?
   c. How would it affect the mechanical advantage of the bicycle if both wheels were reduced 6 in. in diameter, while the chain sprockets were kept constant?
9. *a.* Figure 58 illustrates a device used for clamping, in a certain grinding fixture. The binding action is caused when the tapered slide is drawn back into the stock by the screw and knob, thus forcing the pins outward. Tell which simple machines are used in this arrangement.
   b. Would it affect the holding power of the pins if the slope of the tapered slide were made less steep?

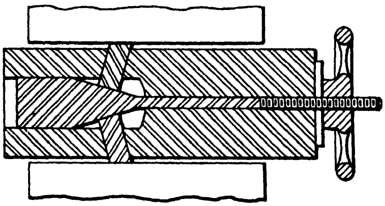


FIG. 58.

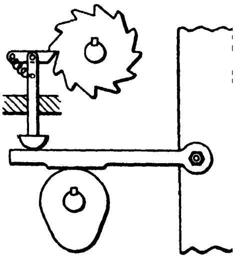


FIG. 59.

10. Figure 59 is an illustration of a mechanical counter, as used on certain automatic machinery. The motion starts with the cam, which rotates and causes the pin to travel up and down, thereby turning the upper ratchet wheel. Examine the sketch and tell which of the simple machines are being used in the device.

UNIT 12. General Applications of Simple and Compound Machines

In the two previous units, the subject matter dealt with the method of recognizing and analyzing various combinations of simple machines, just as they appeared in common appliances and in shop equipment. You were given laboratory compound machines to analyze, and also sketches of other compound machines. These you studied and then discussed on your paper, telling which simple machines were used in the combinations and naming the factors that controlled the mechanical advantage of the devices.

For this unit of work, you are to analyze a whole machine in the same way. The machine is to be a commercial one, and of your own choice. The machine that you choose may be in any one of the shops. Upon receiving permission from your instructor, go to the shop, do your work, and return to your classroom immediately. Make a sketch in the shop of each section of the machine that has one or more simple machines as a part of its make-up, and obtain enough data to enable you to write a complete report.

An excellent method to use in getting your data systematically is to begin at the part of the machine which receives the power from the motor, overhead shafting, or some other source, and observe each moving part in order, through the entire machine. When you have completed your observations and preliminary sketches, you should have data relating to nearly *every important moving part* in the machine.

A well-written, clear report is expected. You are to make a sketch on your report of each section of the machine that contains either a simple single machine, or a combination of several simple machines, and with it write a complete description of just how the apparatus works. Also, as a sort of conclusion to your tests, observe and tell on your report how the force and weight distances compare. In other words, compare the distance that the part of the machine receiving the power travels with the distance through which the last moving part travels, and estimate what the approximate mechanical advantage is, if any.

UNIT 13. Control of Speed by Simple Machines

Previous to this unit, you have been principally interested in the mechanical advantage of simple machines and the factors that control the mechanical advantage. Mechanical advantage, however, may not be the only thing to be considered in the use of simple machines; such things as speed and change of direction may play an important part.

. In the following experiment, you will make tests on a few simple machines to determine whether or not speed may be controlled by the use of simple machines and whether there is any object in thus controlling it.

EXPERIMENT

Figure 60 is an illustration of the micrometers which you are to use in your experiment. Take notice of the "O" mark on the thimble of the micrometer. Now turn the thimble one complete turn and observe how far the "O" mark has moved as compared with the distance that the spindle has advanced.

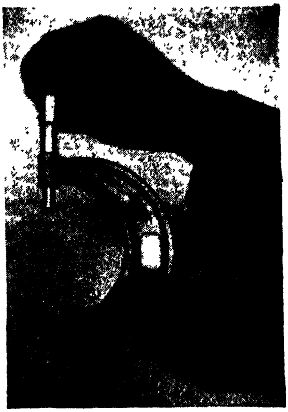


FIG. 60.

Then answer the following questions:

1. How far did the "O" point on the thimble move as compared with the distance that the spindle advanced?
2. What simple machine is embodied in a micrometer?
3. Have you used a simple machine to control the speed of the spindle?

FIG. 61.

General Conclusion A: As your general conclusion, make a statement telling what you have determined regarding control of speed in this simple machine.

As an additional check on your general conclusion, procure a pair of dividers, such as is shown in Fig. 61, and determine for your own satis-

faction how the speed of the points of the dividers is controlled.

Turn the adjusting nut two or three complete turns and note the distance that a point on the edge of the nut travels as compared with the distance that the nut advances on the screw. Note also the distance traveled by the divider points.

Then answer the following questions:

4. What simple machines are represented in the pair of dividers?
5. Would the dividers then operate as a compound machine?
6. Does the speed of the divider points depend on the adjusting nut for its control?
7. Then are you controlling speed through a combination of simple machines?
8. When the nut is revolved, it pushes against a point on the leg of the dividers. What is the speed of this point as compared with the speed of a point on the circumference of the nut?
9. *a.* Compare the speed with which the nut advances on the screw with the resulting speed of the divider points.
   b. What practical advantage is gained by this control of speed in the dividers?
10. *a.* Do you now see the dividers as a compound machine, the speed of whose points depends on a reduction in speed from one of the simple machines in its combination and an increase in speed from the other?
    b. Which simple machine increases the speed, and which machine reduces it?

General Conclusion B: Make a general statement, now, that will cover all cases of speed control, with regard to simple machines when used singly or in combination.

SUMMARY

Fill in the word or words that will make the following statements true:

11. Speed may be controlled by ....
12. Simple machines alone, as well as .... machines may be used to control speed.
13. In cases where there is a great mechanical advantage, the speed of the part being controlled is .... than the speed of the part that controls it.
14. In cases where there is no mechanical advantage, the speed of the part being controlled is .... than the speed of the part that controls it.

ILLUSTRATIONS

1. *a.* Why doesn't a person hold his two hands on a golf club in the way illustrated in Fig. 62?
   b. Is he controlling the speed of the club head with his hands?
   c. What simple machine is represented here?
   d. How can he increase the speed of the club head above that shown in the figure? Explain your answer.

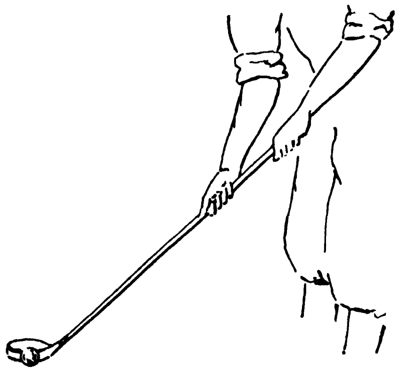


FIG. 62.

2. *a.* Figure 63 shows a roller follower riding on the slope of a cam. The roller moves vertically, and is operated by the cam which moves horizontally. Is the speed of the follower being controlled here?
   b. Is the follower moving vertically at a faster or slower rate than that rate at which the cam is traveling?
   c. What single factor controls the rate of speed of the follower?

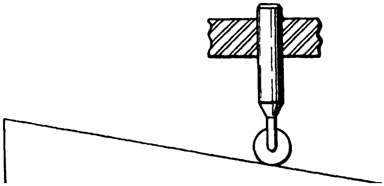


FIG. 63.

3. *a.* From a study of Fig. 64, tell whether the speed of the large pulley is being controlled by the small pulley. The small pulley is the driver and the large pulley is being driven.
   b. Which of the simple machines is being represented here?
   c. Will a larger driving pulley increase or decrease the speed of the large pulley? Explain your answer.

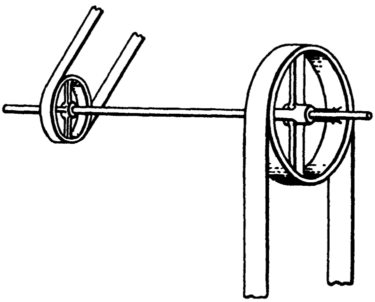


FIG. 64.

4. *a.* Figure 65 illustrates the mechanism of a steam gauge. When the steam flows into the hollow cylinder it tends

to straighten out and incidentally operates the pointer through the gears. What simple machines are represented here?

b. Explain how the speed of the pointer is being controlled.

5. Make a simple line sketch of a child's tricycle and explain in detail how the speed of the vehicle is controlled. Tell which simple machines are involved.
6. Explain just what practical advantage is gained by a change of speed in the micrometers.

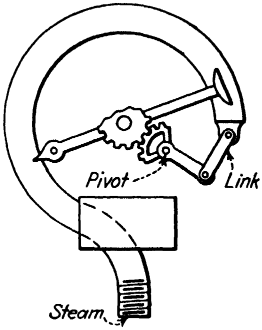


Fig. 65.

UNIT 14. Change of Direction of Motion by Simple Machines

The last point that you are to study, relative to simple machines, is that of direction control. You decided in former units that simple machines could be expected to give you a mechanical advantage when set up correctly, or they could be used to control speed. The question which you are now to determine is, "Can simple machines be used to transmit and control, in a different direction, the motion of a certain force?" For instance, suppose that vertical motion were desired in a machine, but the only possible way for the power end of the machine to move was

in a horizontal direction. Could a simple machine be used to accomplish this? Or suppose that you wanted motion upwards and your force could only act downwards. Could you accomplish this by use of a simple machine?

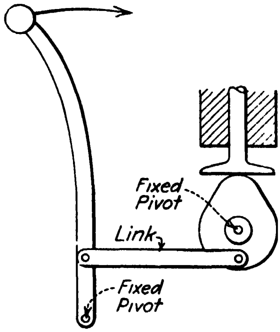


FIG. 66.

The observations that you will make on the simple machines from the following sketches will help you to determine these points in question.

Figure 66 illustrates a device made up of simple machines. Study the sketch. The force is applied at the end of a bar whose other extremity is a fixed pivot. This bar operates a cam and follower by means of a link.

Now answer the following questions:

1. What simple machines, if any, are represented here?
2. If the bar is moved in the direction indicated by the arrow, in which direction will the cam follower move?
3. Have you, then, with this machine the power to transmit and control the direction of motion of the force by means of simple machines?

General Conclusion: Make a statement telling what your observations have proven to you with regard to simple machines and direction control.

4. If you had a case where the force was moving in a downward direction and you wanted your objective to move upward, what single simple machine could you use to accomplish this? Make a line sketch of the setup.

SUMMARY

Copy the following statements on your own paper, and fill in the words which make the statements true:

5. It is possible by using .... to transmit and control the force in any given direction.

6. A wheel and axle may be used to change rotary motion to
.. ..

ILLUSTRATIONS

1. *a.* Figure 67 is an illustration of a jackscrew. In moving the jack handle in the direction shown by the dotted line, how is the force being transmitted through the jack-screw in a different direction?

b. Is the jackscrew controlling the direction in which the force acts?

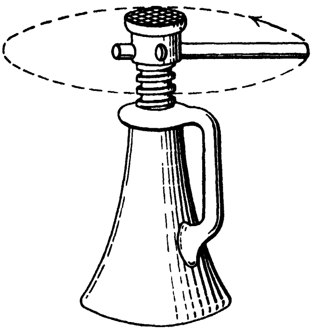


FIG. 67.

2. Explain how the simple machine represented in Fig. 68 is being used to control the direction of motion of the force. The pinion gear is mounted on a fixed shaft and can revolve. The rack is movable and slides in either direction.

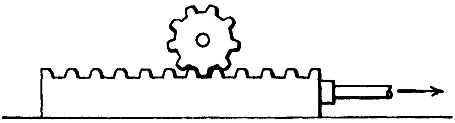


FIG. 68.

3. Figure 69 shows a house being lifted on its foundation by blows on the butt of the object shown between the house and the foundation. Tell which simple machine is being

used here, and explain how it functions in changing the direction of the blow.

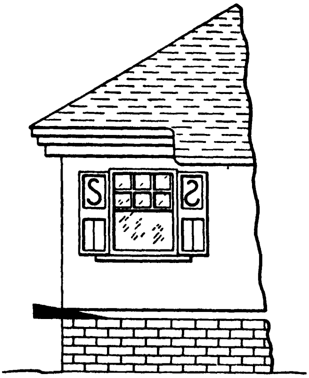


FIG. 69.

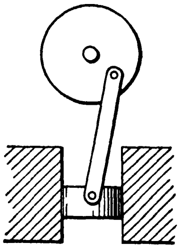


FIG. 70.

4. Figure 70 illustrates a small punch press operated by a flywheel whose link connects to a reciprocating device which runs in guides. Assuming that all the force is derived from the rim of the heavy flywheel, tell which of the simple machines is being used, and explain how it functions in changing and controlling the direction of motion of the force.

UNIT 15. Applications of Control of Speed, and Direction of Motion, by Simple Machines

The foregoing illustrations have shown you a few ways in which the direction of motion of the force may be changed through the use of simple machines. There are many more

such cases in your shop or home. Find at least five cases, other than those mentioned in this unit of work, and explain them in detail. Make a sketch of each.

Then find five other cases where speed is being controlled by simple machines. Make a sketch of each and discuss it in detail on your paper.

BLOCK II

FRICTION

UNIT 1. Sliding Friction

The world in general is living at a much faster pace than the world of thirty years ago. Conditions are changing rapidly. Such things as sailboats, oxen, horses and wagons are not used any more for rapid transportation. The world demands faster motion; airplanes, fast-moving trains, motor cars, and steamers have replaced the old-fashioned slower methods. The same is true in many other types of industrial machinery where single automatic machines have replaced whole batteries of slower machines. Much of this so-called "speeding up" is due to the elimination, in the moving parts of the device, of a factor known as friction.

In the first experiment which you are to do, you are going to find out how friction is produced and then determine the factors that control it. In other words, you are going to make and control friction.

EXPERIMENT

Suspend the box of bricks from a hook by a rope so that it does not touch the floor. Push the box back and forth with your hands, and note the amount of force that it takes to move it about. Then lay the box on the floor and note the amount of force that it now takes to slide it.

Fig. 71.

Fig. 72.

Answer the following questions making a complete statement in answer to each:

1. Did it take more force to slide the box on the floor than to swing it in the air?
2. Did contact between the box and the floor increase the resistance that the box offered to being moved?

Definition: The resistance to motion when one body slides on another is called *sliding friction.*

General Conclusion: Did the contact between the floor and the box produce friction? Make your answer in the form of a general conclusion.

Now that you have produced friction, how can you control it? Surely the friction generated by two bodies in sliding contact is not always the same. Why not experiment with a few of the items that might be able to control the friction, and find the answer to this question? Following is a list of the items that you are to experiment with.

a. You might increase the weight of the object moved.

b. You might change the materials that are being rubbed together.

c. You might change the condition of the surface while keeping the same materials.

d. You might increase the area of the rubbing surface.

For your experiment setup, use the apparatus shown by Fig. 73. Remember, if you wish to find out what effect

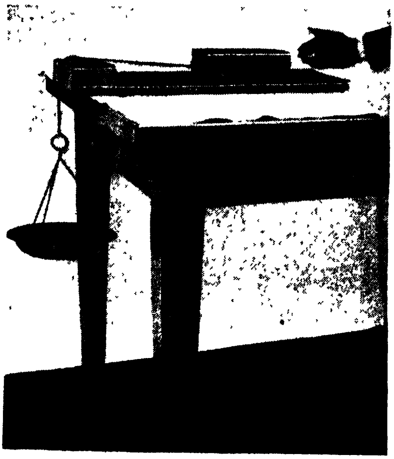


FIG. 73.

changing any one of the items has on the friction, all the others must remain unchanged. Then, any difference noted in the amount of resistance that the object offers to motion will be due to the one item that you changed.

To determine what effect changing the load has on the friction, lay one brick on the board and attach a string and a weight pan to it as shown in the illustration. Put various objects (nuts, bolts, etc.) in the weight pan until you have enough to keep the brick sliding, after it has been started by a push of the hand. The weight of the objects in the pan represents the force necessary to keep the brick in motion and overcome the resistance that the brick is offering to motion. Lay a second brick on the first one, thereby doubling the pressure, and repeat the procedure. Repeat, using three and then four bricks. Record the amount of force necessary to keep the load sliding for each case in a data table similar to the one following.

DATA TABLE

Change of Pressure on Rubbing Surface

Case No.	Load used	Force required to slide the load
1	One brick	
2	Two bricks	
3	Three bricks	
4	Four bricks	

FIG. 74.

Study the results shown in your data table, and answer the following questions:

3. How did the force required to slide the load vary in the four cases that you tried?

4. Does a variation in the amounts of force required to slide the load indicate that the friction between the two materials varies also?

Control Factor: Make a statement telling whether or not the amount of load on the surface controls the amount of friction between the surfaces. State whether or not this item is a control factor of sliding friction.

Next, try changing the materials that are in sliding contact with each other. You can use one of the same bricks, and place a piece of metal on the board, or you can place a piece of cardboard on the board, or any other different material that has a flat surface may be used. You must change nothing but the character of the surfaces in contact. Make and fill out a data table like the one following.

DATA TABLE
Change of Materials Rubbing Together

Case No.	Materials	Force required to slide the load
1	Brick on metal	
2	Brick on wood	
3	Brick on cardboard	
4	Brick on sandpaper	

FIG. 75.

Examine carefully the results shown in the data table and answer the following questions:

5. Did the force required change at all in the four cases that you tried?
6. Would a change in the amount of force required to slide the load indicate that the friction between the surfaces was being varied?

Control Factor: Make a statement telling whether or not the friction between two bodies will vary with the materials in contact. State also whether or not this item is a control factor of sliding friction.

The next item to be considered is the effect, on the friction, of making one of the rubbing surfaces smoother, or rougher, while retaining the same materials.

Use a smoothed and varnished board, then a similar board planed but not varnished, and then try the rough side of the second board. This will give you the effects of three different grades of smoothness for the same material. Follow the same procedure as in testing item *a* and record your results in a data table like Fig. 76.

DATA TABLE
Change in Smoothness of Surfaces

Case No.	Description	Smoothness	Force required
1	Wood planed and varnished	Very smooth	
2	Wood, dry planed	Smooth	
3	Wood, dry rough	Rough	

FIG. 76.

Examine carefully the results shown in the data table and answer the following questions:

7. Did the force required change at all in the three cases that you tried?
8. Would a change in the amount of force required to slide the load indicate that the friction between the surfaces was different when the condition of the surface of the material was changed?

Control Factor: Make a statement telling whether or not the friction between two bodies in sliding contact will vary when the condition of the surfaces in contact varies. State also whether or not this item is a control factor of sliding friction.

The last factor to investigate (unless you have thought of another one you would like to try) is the effect of changing the size of the rubbing surface without making any other change. This can easily be done by sliding the brick on its side, then on its edge, and then on its end. Follow the same procedure as in item *a*, and record the amount of force necessary to slide the brick in each case in a data table similar to the one shown by Fig. 77.

DATA TABLE
Change of Area of Rubbing Surfaces

Case No.	Position	Area	Force required to slide
1	Brick flat	Greatest	
2	Brick on edge	Less	
3	Brick on end	Least	

FIG. 77.

Examine carefully the results shown in the data table and answer the following questions:

9. Did the force required to slide the brick change any in the three cases that you tested?

10. Do your results indicate that the friction between the surfaces was different for each of the three areas?

Control Factor: Make a statement telling whether or not the friction between two bodies in sliding contact will vary when the area of one of the bodies in contact is changed, all other things remaining the same. State also whether or not this item is a control factor of sliding friction.

SUMMARY

Copy the following statements on your paper and fill in the words that make the statements true:

11. Increasing the pressure on two surfaces in sliding contact .... the friction between the surfaces.

12. Decreasing the area of any one body in sliding contact with another, while holding its weight constant ... . on the friction between the surfaces.
13. By varying the materials in sliding contact with each other, the friction between the surfaces ....
14. There is more friction generated when a body slides on a .... surface, than when it slides on a .... surface.

UNIT 2. Illustrations of Sliding Friction

If you did the foregoing experiment correctly, you must have discovered a principle and its control factors. In the following illustrations you are to apply this principle and its control factors. Answer the following questions completely.

1. Skates do not work so well on a very hard smooth board floor as they do upon hard smooth ice. Which control factor explains this difference?
2. Skates with long blades offer practically the same frictional resistance on the ice as skates with shorter blades. Which one of the experiments that you did explains this fact?
3. Skating is less work on smooth ice than on rough ice. Under which control factor does this fact come?
4. It takes more power to move a big boy across the ice on skates than it does to move a small boy. What control factor is involved in this case?
5. Give a good scientific reason why sled runners are shod with iron, rather than with a softer and rougher material.
6. The jackscrew is a machine that uses up more than three-fourths of the energy applied to its handle in overcoming friction. Can you give some good reasons why this is so,

in terms of what you have just learned about friction and its control factors?

7. A simple lever is nearly frictionless. Can you explain why this is so?
8. Why does it take such great force to drive a wedge?
9. Would it take more force to drive a wide wedge under a heavy weight than it would take to drive a narrower wedge of the same length and same thickness at the butt? Explain your answer in terms of sliding friction.
10. Will wide brake bands on an automobile provide more braking effect than narrower bands if the pull on the brake rods is the same in both cases?
11. A shaft turns in a bearing. Is this a case of sliding friction?
12. A shaft turns in a dry babbitted bearing. Would increasing the width of the bearing make any difference in the friction? Explain in terms of facts you have just discovered in your experiment.

UNIT 3. Applications of Sliding Friction

Find, in your shop or outside your shop if necessary, three practical applications of the laws of sliding friction and write out an explanation of each case with sketches to illustrate.

UNIT 4. Friction and Lubrication

Practically every machine that derives its power from moving mechanical parts has the friction factor

to contend with. Friction in these moving parts tends to wear out the machine before the end of its regular term of usefulness and also tends to reduce the work that may be obtained from it. As in the case of the jackscrew, nearly three-quarters of the effort that is applied at the handle is lost in overcoming the friction between the nut and screw. Many other devices which use the principle of such machines as the wedge, the cam, and the differential, lose a good part of the applied effort in overcoming friction.

How can you eliminate this friction? What can be done to the condition of the materials that are in contact with each other, in order that the machine may be made more nearly frictionless? These are the questions which you are to decide for yourself by experimenting with the special apparatus illustrated in Figs. 78 and 80.

EXPERIMENT

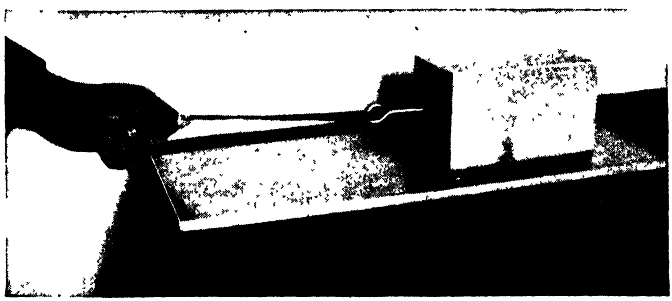


FIG. 78.

Get the flat plate and block shown in the above sketch from your instructor and examine both pieces carefully, making sure that they are absolutely dry. If they are not

dry, wipe them with a piece of cotton waste and a few drops of gasoline. Now place the block on the plate, and slide it with your hands. Note the amount of force that you have to exert on the block, and record your observation in a data table similar to the one following. Then place several drops of machine oil on the rubbing parts of the apparatus and again note the amount of force necessary to slide the block. Record this observation in the data table also.

DATA TABLE

Case No.	Description of apparatus	Force necessary to move when dry	Force necessary to move when lubricated
1	Flat plate and block		
2	Crankshaft and bearings		

FIG. 79.

For the second part of your experiment, use the automobile crankshaft shown in the following illustration. Remove all of the bearing caps.

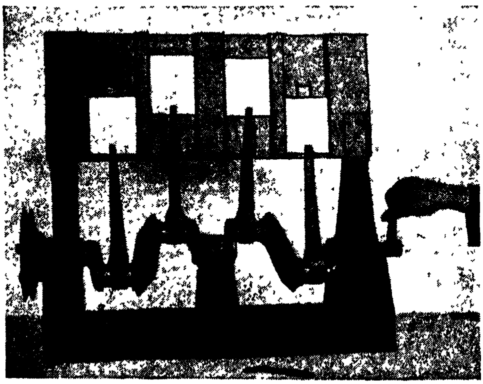


FIG. 80.

Definition: *Bearing caps* are the steel or cast-iron pieces that clamp over the crankshaft and hold it in position on the block.

Wipe all the bearings and bearing caps absolutely dry. Replace the caps, and adjust them just snug enough so that the crankshaft is reasonably firm on the block, and rotates with a bit of stiffness.

Now turn the crank handle and feel how much force it is necessary to apply in order to rotate the crankshaft. Then oil the bearings through the oil holes in the caps, and again rotate the crank. Record all your results in the data table. Use the usual terms to denote any changes in the amount of force required.

Study the results in your data table, and answer the following questions:

1. Did it take more or less force to slide the two materials which were in contact with each other when they were lubricated than when they were dry?
2. If your answer to Question 1 is "less force," would you say that the friction between the two surfaces in sliding contact had been reduced or increased?

General Conclusion: As your general conclusion, state your opinion on the effect of lubrication on materials in sliding contact and tell whether or not the friction was different for flat sliding or rotary contact.

ILLUSTRATIONS AND APPLICATIONS

1. Did you ever notice the driving wheels of a locomotive spin around and slip, when starting on rails that are continually being crossed by automobiles? Try to explain this action in terms of your experiment.

2. Would it affect the braking of an automobile if oil was allowed to get in between the brake bands and the drums? Explain.
3. *a.* Two gears running together showed considerable wear after a short term of service. What would you suggest as a remedy for reducing the wear on the gears? Explain why.

   b. Draw a sketch of two gears in mesh with each other and indicate where the friction occurs.
4. Would it be more expensive to run a car whose bearings were poorly oiled than one whose bearings were well oiled? Explain why.
5. Would it be of any advantage to have the threads of a bolt and nut lubricated if the bolt were going to be tightened into a permanent position on a vibrating part of an automobile? Why?
6. Find at least three other practical cases, in your shop or house, that will illustrate the effect of lubrication on friction. Make a sketch of each case, and discuss it briefly. (At least one of the cases should be an example of flat surfaces.)

UNIT 5. Friction Reduction by Mechanical Means

You learned that friction is produced by two materials that are in rubbing contact with each other, and that this friction can be reduced somewhat by proper lubrication. It is not practical in every case, however, to merely lubricate the two principal materials so that they may slide easier; mechanical

means of reducing friction are sometimes more applicable to the situation. Your experiment is a study of the current methods that are being taken to reduce friction in machines as small as the tiniest portable drills and as large as the steam engine. Since the most common way that friction is produced in a machine is by the rotation of a shaft in a bearing, the first piece of apparatus which you will experiment with will be a shaft and a bearing, as illustrated by Figs. 81 and 82.

EXPERIMENT

Get the shaft and bearing from your instructor, and after examining both pieces, wipe them clean with a piece of waste and a few drops of gasoline. Now insert the shaft in the bearing and rotate it with your hands. Note how much force is necessary and record your result in the data table.

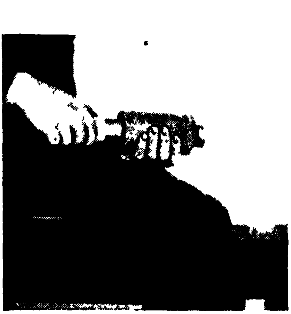


FIG. 81

FIG. 82.

Slide the shaft out of its bearing, and place it in the ball bearing as shown in Fig. 82. Rotate the shaft again, and record the amount of force necessary now to keep the shaft in motion.

DATA TABLE

Case No.	Description of apparatus	Force needed with plain bearing	Force needed with ball or roller bearings
1	Shaft and bearing		
2	Flat plate and block		

FIG. 83.

For the second part of the experiment you are going to investigate the means employed to reduce friction in materials that are in rubbing contact in a straight line, rather than in a rotary fashion.

Use the same flat plate and steel block that you used in the last experiment. Wipe both pieces free of any oil or moisture; then slide the block on the plate and note how much force is required. Record your result.

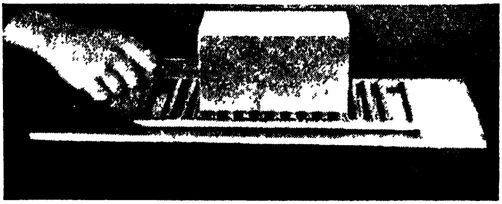


FIG. 84.

Now place the set of rollers under the block, as shown in Fig. 84. Slide the block again and note the amount of force necessary. Record this observation in the data table also.

Refer to your data table and answer the following questions, making a complete statement in answer to each:

1. How did the force required to slide the materials on plain bearings compare with the amount of force required when ball or roller bearings were substituted?

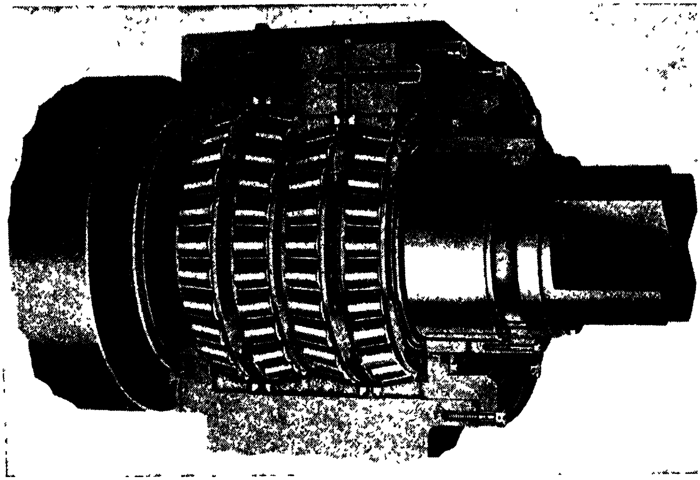
2. Has the friction been reduced or increased by the use of the ball or roller bearings?

General Conclusion: Make a general statement telling whether or not you have demonstrated to your own satisfaction that the friction between any two surfaces in contact with each other may be reduced by mechanical means.

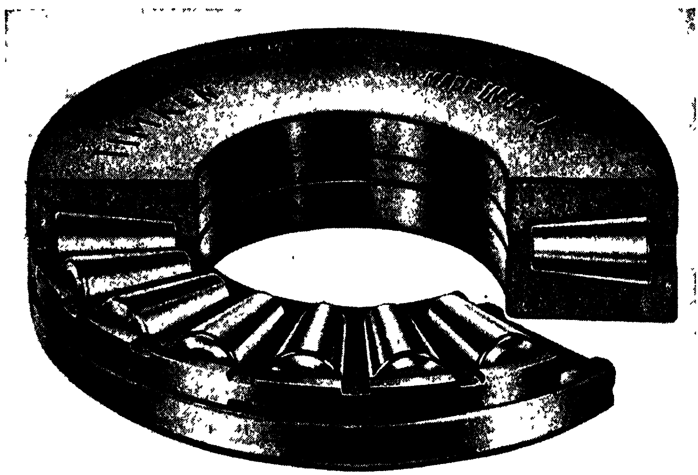
ILLUSTRATIONS AND APPLICATIONS

1. The surfaces near the ends of an axle of a large horizontal electric generator were found to be exceedingly worn after only a short term of service. The wear might have been due to several causes. If you had the job to investigate the cause for the wear, explain just what you would look for and how you would remedy the condition.
2. A gyroscope (*see* dictionary) is a device used for keeping bodies in equilibrium (balance). The flywheel of the apparatus must run smoothly and continuously. Explain whether or not it would be advisable to have cast-iron bearings, or roller bearings, for the flywheel of a large gyroscope.
3. Get permission from your instructor to go to one of the shops in the building, and try to find at least four cases where ball or roller bearings are being used on machinery. Draw a sketch of the part of the machine that has the bearing and explain why the use of expensive ball or roller bearings is warranted on the machine.

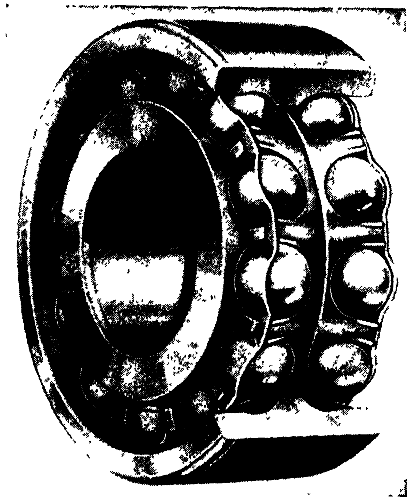
For an interesting treatise on many kinds of roller bearings see the book published by the Timken Roller Bearing Company, entitled *Wherever Wheels and Shafts Turn.* This book may be in your instructor's bookcase. Ask him to lend it to you. Read carefully the parts of the book that tell of the many applications that the bearings have in commercial machinery.



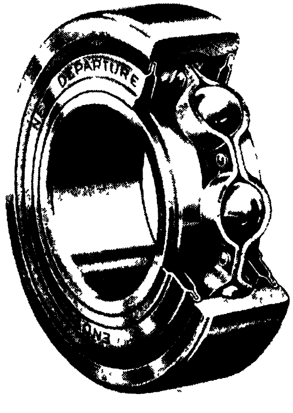
Tapered roller bearing. A four-row, steel-mill, roll-neck bearing (*Timken Roller Bearing Company.*)



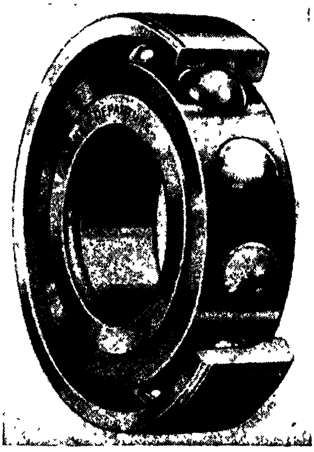
A tapered-roller thrust bearing. (*Timken Roller Bearing Company.*)



Double-row radial-thrust-type ball bearing. (*New Departure Company.*)



Ball bearing. Single-row radial-type with oilseal. (*New Departure Company.*)



Single-row thrust-type ball bearing. (*New Departure Company.*)

Another very interesting passage to read on the types and applications of ball and roller bearings may be found in *Mechanics* by L. R. Smith. See pages 106 to 110 inclusive.

Your instructor may also have a sample display of real ball and roller bearings donated by the manufacturers of the articles. If such is the case, spend a few minutes examining the display. Note the range of sizes, the construction, and try to visualize where you have seen similar bearings in operation.

UNIT 6. Useful Friction

Because your objective until now has been to reduce friction by such methods as lubrication, ball and roller bearings, you must not conclude that all friction must be eliminated at all times. For instance, suppose that it were possible to eliminate friction entirely in a regular, commercial-size steam roller. Have you any idea how you would proceed to stop the machine after it had once reached its top speed?

Then there are other cases such as are found in the following questions, which you are to answer:

1. When you walk on a dry pavement, why is it that your feet do not slip out from under you?
2. Why are chains used on automobile tires in the wintertime?
3. Why does a new tire hold the road better than a smooth tire that is worn through to the fabric?
4. What causes the pressure of a brake band on a drum to slow down the speed of a vehicle?

5. Why do train engineers sometimes drop sand ahead of the wheels when attempting to slow down?

General Conclusion: Your answers to the foregoing questions should make it clear in your mind whether or not friction may be a useful thing. For your general conclusion make a statement covering the point.

ILLUSTRATIONS AND APPLICATIONS

1. If there were no friction between the tires of a car and the road, would the car ever stop? Explain.
2. If there were no friction between the plates of a clutch in an automobile, would you be able to get any motion from the car? Explain.
3. What is it that prevents a jackscrew from turning in the nut and automatically lowering itself, when a load is placed on top of the jack?

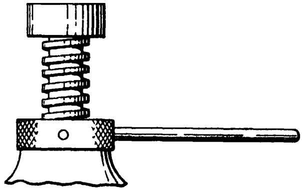


Fig. 85.

4. What is it that prevents the ladder shown in the sketch from moving in the direction shown by the arrow?

Fig. 86.

5. Explain why a bicycle rider traveling at a high speed around a curve can safely lean considerably toward the

inside of the curve, without fear of his tires slipping out from under him.

6. If such a thing as friction were unknown, and were not present in our everyday life, how hard would you have to push a heavy steel table to slide it on the floor if you had your own back against a wall?

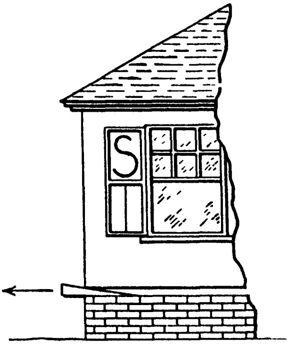


Fig. 87.

7. In lifting a house on its foundation with a wedge, explain why the wedge does not "pop" back out in the direction of the arrow after each blow is struck on its butt. Under what conditions might it do so?

8. Examine some machine in your shop, and list the places on the machine that involve friction. Also list whether the friction at each point is a detriment or an asset. For instance, "The Automobile":

Data Table

Part	Friction is a help	Friction does not help
Tires on road	✓	
Clutch	✓	
Main bearings		✓
Etc.		

Fig. 88.

9. Sometimes it is necessary to transmit power at different angles as shown in the following sketch. The pulleys are made of wood or steel and covered with leather. Why is it necessary to keep both pulleys free of oil?

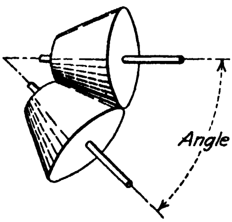


Fig. 89.

10. It is possible to hold a boat to a dock landing by winding the rope around the support as shown. This practice is called "snubbing." Explain why it is that a large boat can be held thus by snubbing, when an ordinary straight pull on the line would require the strength of a dozen men.

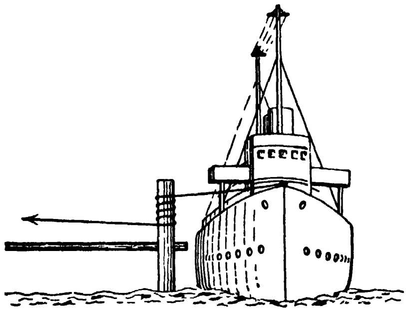


FIG. 90.

11. Make sketches of, and explain briefly, at least five cases where friction is used to some advantage. Also find five other cases of friction where it is not an advantage.

BLOCK III

WORK—POWER—EFFICIENCY

UNIT 1. Work

Work, as you are to understand it henceforth in science, does not have the meaning that you attach to it in the everyday sense; namely, labor. It does not necessarily mean that because more work is produced more strength is used, or that all work is labor. Work is something more technical, and it can be measured.

Definition: *Work* is the result of a force acting through a distance.

From the definition, you can readily see that the work being done by a machine can be measured simply by noting the force acting and the distance through which it moves. The actual calculations, however, involve multiplication, as shown by the following formula:

$$\text{Work} = \text{force} \times \text{distance}$$

Work is done when a hoisting engine lifts concrete, when a man climbs a mountain, when a horse draws a wagon behind him, and when an automobile is stopped with brakes. In each case, you will note that a force is acting through a distance to accomplish the work.

You must remember that no work is done where the force does not move through a distance.

Work is also independent of the time that it takes the force to move through the distance. For instance, one man lifting a heavy load of bricks in a certain time does exactly the same amount of work as another man who lifts the same load through the same distance, but in one-half the time.

The unit for measuring work, used in science, is the amount of work done when a weight of one pound is lifted a distance of one foot. This unit is called the foot-pound (ft. lb.). It is evident that for straight lifting the amount of work done in foot-pounds can always be found by multiplying the weight of the object by the number of feet through which it is lifted. If, however, the object is slid along a flat plane instead of being lifted, the work done will be quite different, even though the object moves through the same distance. In this case the work done in foot-pounds will be the force exerted on the object in order to slide it, multiplied by the distance the force moves through. The foregoing statements may best be illustrated by the following examples:

A. A hoisting engine that lifts a load of 750 lb. through a height of 80 ft. will do

$$\begin{aligned}\text{Work} &= 750 \times 80\\ &= 60{,}000 \text{ ft. lb.}\end{aligned}$$

B. A man who is sliding a 200-lb. packing case along a floor with a steady push of 50 lb., for a distance of 30 ft., will do

Concrete mixer. (*Jaeger Machine Company.*)

$$\text{Work} = 30 \times 50$$
$$= 1500 \text{ ft. lb.}$$

ILLUSTRATIONS OF WORK

Answer the following questions in detail, making a complete statement in answer to each:

1. Ten men lined up, each in back of the other and pushed against the side of the Woolworth Building with all their strength, but the building did not budge. The average weight for each of the ten men was 180 lb. How much work did they do? Why?
2. One man lifted a heavy casting from the floor to the machine, a distance of 3 ft. Another man lifted a casting, weighing twice as much, through a distance of 18 in. How does the work done by the first man compare with that done by the second? Explain your answer.
3. Two boys were carrying water for bricklayers who were working on a scaffold 40 ft. above the height of the water tank. One boy made 50 trips in an 8-hr. day carrying a pail of water in each hand. The other boy made only 25 trips in 8 hr. and carried a single bucket each trip. How much more work did one boy do than the other? Explain.
4. Can a force be used without doing work? Give two examples.
5. A train pulling a load up a grade is forced to stop when halfway up and is only able to keep the load from sliding back. Is the train doing any work? Why?
6. If the train mentioned in Problem 5 were unable to keep the load from sliding back, would any work be done? Explain.
7. Allowing that there is a friction loss in a differential hoist, on which end of the hoist is more work done; on the hand chain or the weight hook? Explain.
8. Is more or less work done when a heavy machine casting is lifted vertically a certain distance by a winch, or when it is slid along the floor the same distance? Explain.

9. A punch exerts an average pressure of 50 tons in punching a hole through a plate $1\frac{1}{8}$ in. thick. Compute the work done in foot-pounds.
10. With a long lever and a pry-to-bite relation of 10 to 1, a man lifted a $\frac{1}{4}$-ton casting 2 in. How much work did he do?
11. A man lifted a 50-lb. keg of white lead from the ground to the tailboard of a truck 4 ft. above the ground. How much work did he do?
12. A passenger elevator weighed 1600 lb. when loaded. How much work was done, if it ascended 30 stories, each story of the building being approximately 12 ft. high?

APPLICATIONS OF WORK

Find at least three cases in your own shop or home life that are good examples of work being done. Make a brief report on each case.

UNIT 2. Power

In your study of work, you were given to understand that time is not a factor that enters into consideration in finding the work done by any person or machine. With power, the case is different. Time is the one thing that determines power. For example, it is possible, under certain conditions for a light horse to do as much work as a heavy horse, provided the light horse is allowed more time to complete his work. The heavy horse is said to possess the greater power,

however, since he can do the work in a shorter time. Power concerns itself with both the work done and the time. A locomotive will do many times as much work in a given time as a hoisting engine, and therefore has the greater power.

Definition: *Power* is the rate of doing work.

Expressed as a formula the above definition becomes

$$\text{Power in foot-pounds per minute} = \frac{\text{work done}}{\text{time in minutes}}$$

This is the usual form for the power formula. If the power for a period of a second or an hour is desired, the above formula may be either divided or multiplied by 60, as the case may be.

The most common unit of power is the horsepower.

Definition: Power that is being delivered or consumed at the rate of 33,000 ft. lb. per min. is called a *horsepower* (hp.).

The definition of power is based on someone's idea that a horse can lift 33,000 lb. through a distance of one foot in a minute. Although some horses can lift more, and some can lift less, the horsepower has become our standard unit. To find the horsepower of a device mathematically, the power in foot-pounds per minute is divided by 33,000.

$$\text{Hp.} = \frac{\text{ft. lb. per min.}}{33{,}000}$$

The unit of power in the metric system is called the watt.

Power transmission by belt drive. (*Allis-Chalmers Manufacturing Company.*)

Definition: The *watt* represents the amount of work done by one ampere of current under a pressure of one volt.

In your consideration of power, however, you are not interested in how watts of power are produced as per the electrical theory; you are interested only in the fact that the watt is the electrical unit of work. In a practical sense, the number of watts used or produced in an electrical circuit is as follows:

$$\text{Watts} = \text{volts} \times \text{amperes}$$

There are 1000 watts in one kilowatt, or as it is usually abbreviated, kw. The kilowatt is used almost universally in connection with electrical power measurement. If you will take the pains to look at the meter in your home that measures the electricity you use, you will notice that you are buying electricity by the kilowatt.

The kilowatt is equivalent to $1\frac{1}{3}$ hp. With this statement, then, it is a simple matter to convert mechanical power units to electrical units or vice versa.

ILLUSTRATIONS OF POWER

1. Two centrifugal pumps work at filling a tank. The first fills $\frac{3}{4}$ of the tank in 3 hr., while the other pump fills the other $\frac{1}{4}$ of the tank in 1 hr. Compare the power of both pumps.
2. A freight elevator in a large building carried a total of 150,000 lb. of freight from the basement to the upper floor over a period of 8 hr. Another elevator in the same building carried the same amount of freight through the same dis-

tance but did it in one-half the time. Which elevator possesses the greater power? Explain your answer.

3. If one gun shot a 400-lb. projectile through a distance of 11,500 ft. in $1\frac{1}{2}$ seconds, and another gun shot a similar projectile through one-half the distance in one-half the time, which gun would have the greater power? Explain.
4. A train running between Boston and New York carried 8 coaches the entire distance in 9 hr. Another train carrying 16 similar coaches made the same trip in one-half the time. Compare the horsepower of both trains. How much more horsepower did one train have than the other?
5. A man weighing 180 lb. climbs a ladder through a vertical distance of 45 ft. in $1\frac{1}{2}$ min. What horsepower did he expend?
6. A triplex pump lifts 4000 lb. of water a vertical distance of 60 ft. in 2 min. Compute the horsepower of the pump.
7. A hoisting engine is being used to lift concrete to the top of a building 50 ft. high. If 1000 tons of concrete are taken to the roof each working day of 8 hr., what is the average horsepower expended by the engine?

APPLICATIONS OF POWER

Find at least three cases in your own shop or home life that are good examples of power. Make a brief report on each case.

UNIT 3. Efficiency

From your experiments with friction, you will recall that, as a general rule, nearly every moving

part of a machine has friction, and that as the friction increases in a machine, the usefulness of the machine diminishes. This measure of a machine's usefulness with regard to the work put in is called its efficiency.

Definition: *Efficiency* is the ratio of the output of a machine to the input.

In order to make the above definition more clear in your mind, note the following comparison.

Two machines are being operated by a man who uses the same pressure on the foot pedal of both machines independently. The two machines are identical in every respect. If the man found that the first machine could not quite punch holes through stock ½ in. thick while the other machine could, the machine that would have the greater efficiency would be the second machine. It would be more efficient simply because an output of more work could be obtained from it than that obtained from the first machine, with the same input.

Efficiency may be expressed mathematically in per cent; for example, If it takes 75 ft. lb. of work to operate a machine and 50 ft. lb. of work is all that the machine does, the efficiency of the machine is:

$$\begin{aligned} \text{Efficiency} &= \frac{\text{output}}{\text{input}} \\ &= 50/75 \text{ or } 2/3 \\ &= 66\tfrac{2}{3} \text{ per cent} \end{aligned}$$

ILLUSTRATIONS OF EFFICIENCY

1. Two machines of the same kind were tested and the results showed that if the same amount of work was put into both

machines, the first machine would have an output of 10 ft. lb. less than the second. Which machine has the greater efficiency? Why?

2. Three generators consuming the same horsepower for the input have an output as follows:

First generator	75 kw.
Second generator . . .	78 kw.
Third generator.	72 kw.

List the generators in their order of efficiency.

3. If the efficiency of one of two generators is rated as 72 per cent, and the other as 85 per cent, what can you say about the amount of power being delivered to each of the generators, allowing that both are identical and actually deliver 200 kw. each every hour?

4. As additional applications, find the efficiency of the jackscrew, double fixed and double movable block and tackle, and the $\frac{1}{4}$-ton chain hoist. First, take the jackscrew and load it with 60 lb. of weight, in the same manner that you handled the experiment on the jackscrew in Block I. Hook a scale over the end of the long handle and get a reading in pounds for the amount of force necessary to lift the load. Record this in a data table similar to the one following.

Data Table

Case No	Name of machine	Weight lifted	Force needed	Distance force traveled	Distance weight traveled	Work put in	Work done	Efficiency in per cent
1	Jackscrew							
2	Block and tackle							
3	$\frac{1}{4}$-ton chain hoist							

Fig. 91.

Record the force distance and also the distance through which the load moved for one complete turn of the nut. In filling in the "work put in" and "work done" columns, remember that the force in pounds multiplied by the distance that it moves through is the work in foot-pounds.

5. It takes 4 lb. of force to raise a load of 20 lb. through a distance of 3 in. on a differential hoist. The distance through which the force moves is 18 in. What is the efficiency of the hoist?

6. How much work in foot-pounds would you have to put into a wheel and axle that was 80 per cent efficient, if the required output of the machine was 650 ft. lb.?

APPLICATIONS OF EFFICIENCY

Explain on your paper how you would proceed to find the efficiency of at least three pieces of your own trade machinery. Tell in detail where the input comes from, is delivered to, and how it is measured; also tell how the output of the machine is utilized to do work.

BLOCK IV

PARALLEL FORCES

UNIT 1. Parallel Forces

Since you are going to be constantly in contact with the term "parallel forces," the first thing that you should learn of the subject is its definition. The following will serve to define parallel forces.

Definition: *Parallel forces* are those forces which act on a body in such a manner that their lines of action are parallel.

The forces need not act in the same direction, but may act in opposite directions, and still be called parallel forces, as long as their lines of action are parallel. The following figure illustrates the points. The four forces A, B, C and D are acting on the bar in different directions; their lines of action are parallel, however.

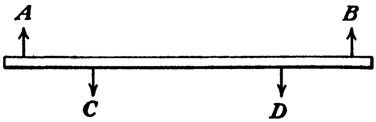


FIG. 92.

The forces acting downward in the legs of a table and the forces acting downward on a bridge are good examples of parallel forces. In the shops pulleys and belts mounted on overhead shafts and in a building

the weights of the various pieces of furniture acting downward on a floor constitute parallel forces. There are many more common examples of parallel forces about you, but for the present the foregoing examples will suffice.

Now, knowing that in each of the above-mentioned cases, the forces act down, why is it that the whole object does not move with the forces? Why is it that the object just remains at rest,.in spite of the forces acting down on it? That is your assignment for this experiment. You are to find out what the relation is that exists between parallel forces acting in one direction and the forces which oppose them.

EXPERIMENT

Hang a bar from a beam as shown by Fig. 93. Either a steel or wooden bar may be used; note its weight before you hook it up. Use a pair of 25-lb. spring scales to support the bar on the ends.

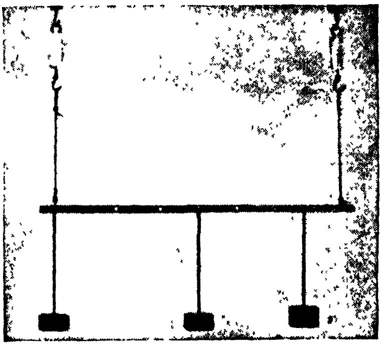


Fig. 93.

Now place two or three weight hangers and weights along the bar in any of the holes provided, and read the

results shown on the two scales. Then, by adding together the individual weights, find the sum of all the forces acting down.

Answer the following questions with complete statements:

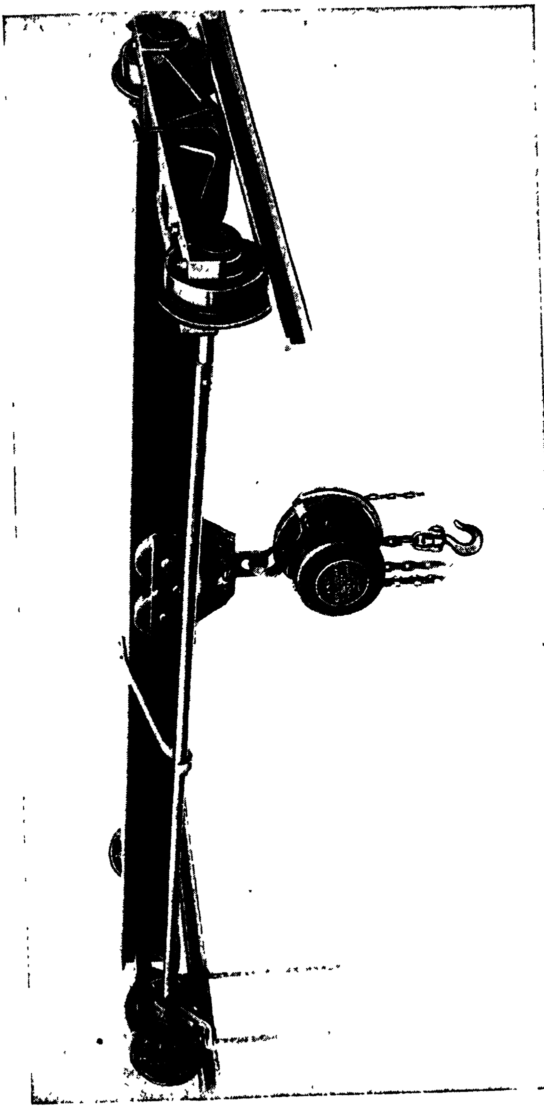
1. Does the total weight of the bar, the load hangers, and the standard weights represent the total force acting downward on the bar?
2. Does the sum of the scale readings represent the total force acting upward on the bar?
3. Since the bar does not move under the impulse of any of the forces acting on it, what can you assume about the relative strength of the two opposing sets of forces? Does your answer check with the results obtained in the experiment?

General Conclusion: As your conclusion, make a general comparison between any two sets of opposite parallel forces. Assume that the object acted upon is not moving, and that the lines of action of the forces are parallel.

Experiment with the apparatus to see whether or not a change in the position of the load will change the magnitude of the supporting forces. Place all the load near one of the ends of the bar, and notice the readings of both scales. Then shift the load to the other end of the bar. Observe the scale readings again. Notice the scale readings when all the weight is in the middle of the bar.

Answer the following questions, making a complete statement in answer to each.

4. When the weight was placed entirely at one end of the bar, what did you notice about the reading of the scale on that end, as compared with the scale reading for the opposite end of the bar?



Spur-geared hoist suspended from I beam. Illustrates parallel forces. (*Yale and Towne Manufacturing Company.*)

5. When the weight was placed in the middle of the bar, how did the readings of both scales compare with each other?

Control Factor: Referring to your answers to the two preceding questions, make a statement telling what single item will control the variation on each of the supports, while keeping the sum of the supporting forces constant.

UNIT 2. Illustrations and Applications of Parallel Forces

1. Suppose that two painters were pulling a scaffold up by using a block and tackle and that, owing to the heavy load that they had on the scaffold, both painters together could not lift the loaded end of the scaffold. Would it be of any use for them to pull up the scaffold from the opposite end, as shown by the sketch?

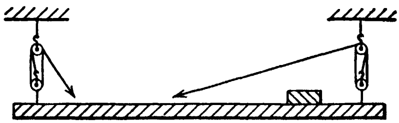


FIG. 94.

2. A light and a heavy horse are hitched together. About where must the kingpin in the evener be placed in order that the light horse shall pull less than the heavy horse? Explain by use of a sketch.
3. A railroad trestle is supported by abutments made of concrete. A locomotive begins to cross the bridge as shown. Explain how the pressure on each of the abutments

will vary as the train crosses the bridge from one side to the other.

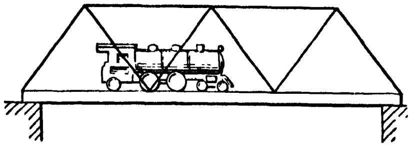


FIG. 95.

4. A planer in a machine shop is set up to cut a piece of steel as shown in Fig. 96. Which support, *A* or *B*, will be forced to receive the greater part of the pressure? Does this tie up with any one control factor of your experiment? Which one?

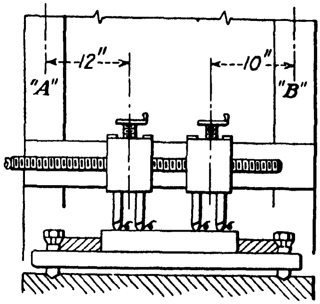


FIG. 96.

5. Explain how the pressure on the lathe centers, shown by Fig. 97, varies as the tool cuts a chip while moving in the direction indicated by the arrow.

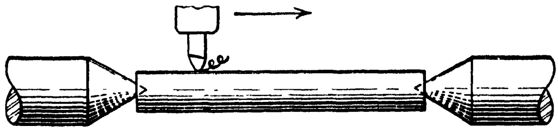


FIG. 97.

6. Shafts in a mill are hung as shown in the following sketch.

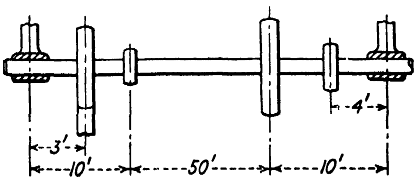


FIG. 98.

The four pulleys which take their power from the shaft exert the same downward pressure on the shaft regardless of their size. Explain which shaft hanger will be forced to support the greater part of the load. Does this fact tie up with any one control factor of your experiment? Which one?

7. The loads shown in the following sketch indicate the weights of several articles resting on a floor, and supported by two beams, *A* and *B*. What is the total pressure that both *A* and *B* must stand? Which support, would you judge from the sketch, would have to support the greater part of the load?

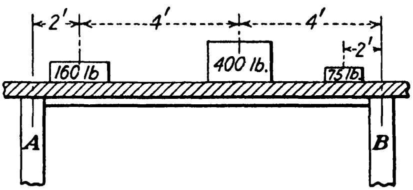


Fig. 99.

8. *a*. Provided that the shaft, upon which the three pulleys are mounted, is *rigid*, study the sketch and explain which support will have to resist the greater pressure.

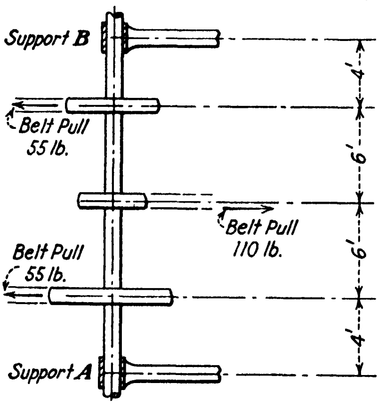


Fig. 100.

b. Explain by a sketch and arrows the direction of the pressure on each bearing.

9. Find at least five other everyday-life cases wherein the principles of parallel forces apply. Make a sketch of each case, and discuss it in detail on your paper.

UNIT 3. Beam Deflection

In the two preceding units on parallel forces, you learned that the sum of the pressures acting downward on a beam had a positive relation to the supporting forces when the beam was in equilibrium. This is an important principle. There is another principle, however, one which you are about to consider by experiment. This new idea is called beam deflection.

Definition: *Deflection* in a beam is that distance that a beam sags, below the normal horizontal level, when bearing a load.

EXPERIMENT

Support a piece of white pine 10 ft. × 2 in. × 4 in. on two horses as shown by Fig. 101. From a point midway between the supports, suspend the loaded box of bricks. Observe what happens to the shape of the piece of pine.

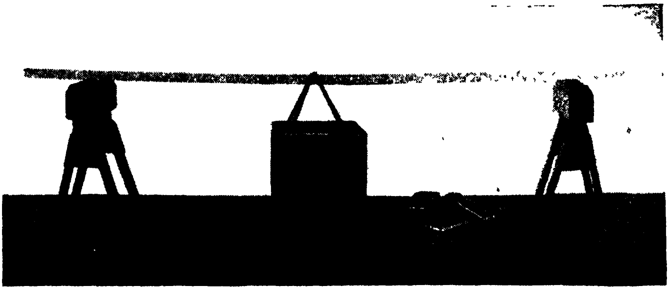


Fig. 101.

Using your observations as the basis for your answers, answer the following questions:

1. When the load was hung from the beam, was there any change in the beam from its normal position?

General Conclusion: Make a general statement, now, in which you explain your conclusions regarding the effect of a load on a beam.

2. Would your general conclusion also apply in the case of a cantilever beam? (If you are in doubt, make a test setup.)

Definition: The part of a beam that projects from a wall, or beyond a support, is called a *cantilever beam.*

Not all beams deflect the same amount, and so it will be your task now to determine what the factors are that control the amount of deflection in a beam. There are several items that you might consider as control factors to experiment with; following are a few which you may use to start off.

Item 1. The effect of changing the length of the beam between the supports, or as in the case of the cantilever beam, the effect of changing the length of the beam overhanging the support.

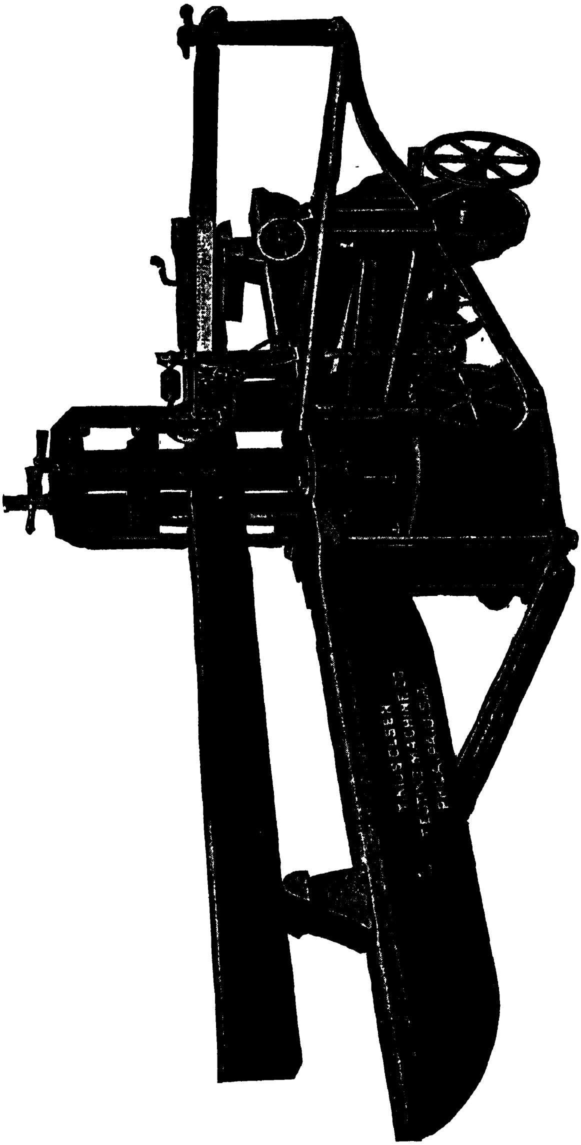
Item 2. The effect of changing the width of the beam.

Item 3. The effect of changing the thickness of the beam.

Item 4. The effect of varying the load on the beam.

Add as many more items as you like to this list of those that you intend to consider experimentally as control factors and then follow the regular procedure given below in determining whether or not each individual item really does control the amount of deflection in a beam. Answer the same pair of questions for each individual case.

First, consider Item 1. Support the long 2 in. × 4 in. on the two horses as you did the first part of the experiment. Then, using the same load on the beam for each case, move



Machine for testing beam deflection. *(Tinius Olsen Testing Machine Company.)*

the horses closer together or farther apart as the case may be, thereby obtaining a shorter or longer beam length. Observe the amount that the beam deflects for each case, and record your results in the data table. Use the usual terms, "a little more," "less," "even more," "the greatest," etc. to denote changes in the amounts of deflection.

DATA TABLE

Case No.	Length of beam	Amount of deflection	Ability to resist deflection
1	Very long		
2	A little shorter		
3	Even shorter than Case 2		
4	Very short		

FIG. 102.

Answer the following questions, making each answer in the form of a complete statement:

3. Did the variation in the item you experimented with affect the deflection of the simple beam? Would it affect the cantilever beam?

Control Factor: Can you call the item in question a control factor? If so, state your answer as a control factor.

Repeat the procedure for each of the other items that you listed, making a data table for each case and answering the same questions for each individual item.

Now, consider Item 2. Keeping all the other factors constant, vary the width of the beam. Take three observations: one with the beam used lying on its broad side, another observation with the width increased by a second beam, and a third observation with the width increased by still another beam.

Next, consider Item 3. Keeping all the other factors constant, vary the thickness of the beam. Take three observations: one with the beam used lying on its broad side, another observation with the thickness increased by a second beam placed on top of it, and a third observation with the thickness increased by still another beam.

Finally, consider Item 4. Keeping all the other factors constant, vary the load on the beam. Take four observations: when the box is full, three-quarters full, half-full, and empty.

Continue experimenting now with any other items of your own choice that you wish to consider as control factors.

7. What about the material used in the beam?

UNIT 4. Illustrations and Applications of Beam Deflection

1. In some of the old factories that still have wooden floors, it is a general rule that the center aisle must never be stocked with heavy cases, boxes, trucks, etc. Explain why this rule is a safe one.
2. *a.* The following sketch is that of a tool on a machinist's shaper. When the cutting edge of the tool is engaged in work, what type of beam does it represent?

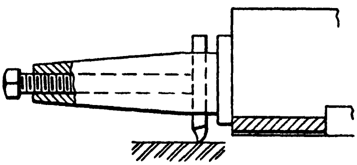


FIG. 103.

   b. If the tool did not prove rigid enough for the work, explain what you might do to the same tool to make it so.

3. *a*. In the jackscrew test illustrated in Fig. 104, the object is to determine the breaking stress of the piece of wood. How would it affect the pull required on the end of the jackscrew handle if the thickness of the piece of wood were increased?

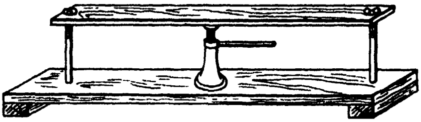


FIG. 104.

b. To which control factor can you tie up your answer?

c. How would it affect the amount of pull required on the handle if the jack were moved over very close to the left-hand support, and how do you account for it?

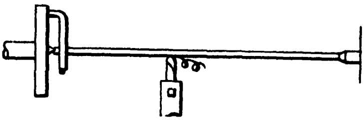


FIG 105.

4. *a*. Is it practical to take a heavy cut off a thin rod as shown by Fig. 105? Why?

b. To which control factor can you tie up your answer?

5. The most important problem that the builder of a regular bridge has to deal with is that of the elimination of deflection in the bridge. If you were the bridge builder, how would you go about building a bridge that would be as nearly perfect as possible with regard to deflection?

6. If a pine floor were sagging at its midpoint, as shown in the following sketch, and you were given the job of remedying

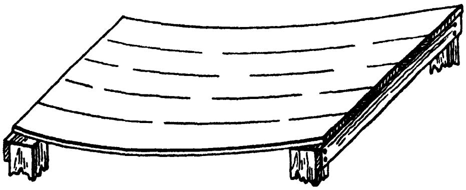


FIG. 106.

the case, name and explain in detail the methods you know of which might be used as remedies for the situation.

7. *a.* If thin glass is so very cheap to manufacture, why isn't it used for table tops, such as those of science tables, instead of more costly rubber compounds? Explain your answer.

   b. How about using thick glass? Explain your answer.

8. The following sketch illustrates a hold-down clamp on a piece of apparatus. If the inflexibility of the clamp is an important factor in holding down the piece of metal, how would it affect the deflection of the clamp:

   a. If the thickness of the clamp were reduced from 1¼ in. to 1 in.?

   b. If the steel clamp were replaced by a pine-wood clamp? Explain your answers in terms of the experiment.

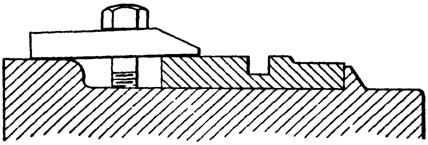


FIG. 107.

9. Explain how the principles of deflection apply in the following cases. Examine each case; then tell how and why you would change each of these cases in order to reduce their deflection:

   a. A beam protruding from a window with a man on the outer end.

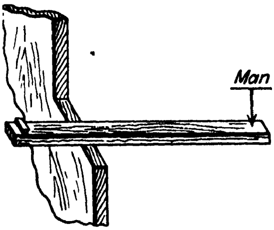


FIG. 108.

b. A rotating pulley on the end of a shaft.

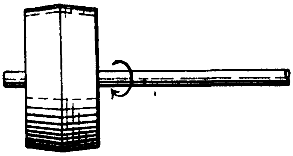


FIG. 109.

c. A painter on a scaffold.

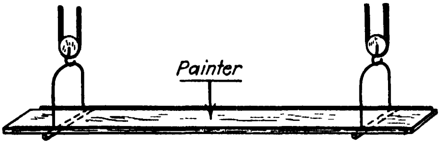


FIG. 110.

10. Bring in to class a written discussion of at least three other practical cases of beam deflection, preferably from the shop. Make a sketch of each case, and discuss it in detail.

UNIT 5. Surface Tension and Compression

In the study of surface tension and compression, which you are about to begin, you are going to be given a chance to observe what happens in a beam when it bears a load. It is quite obvious to you that the deflection caused by beams bearing a load is not always noticeable; that is, the beams do not sag under the load to such an extent that the deflection is visible to your eye. In the experiment that you are to do, the case of the beam deflecting an enormous amount

under a load will be taken, in order that the principles involved in the subject may be more clearly illustrated. The same principles apply to all cases of beams, however, whether they show their deflection or not.

EXPERIMENT

Procure from your instructor a piece of wood, about four feet long having saw kerfs or notches cut into one side of it for every consecutive inch of length, as shown in the following figure.

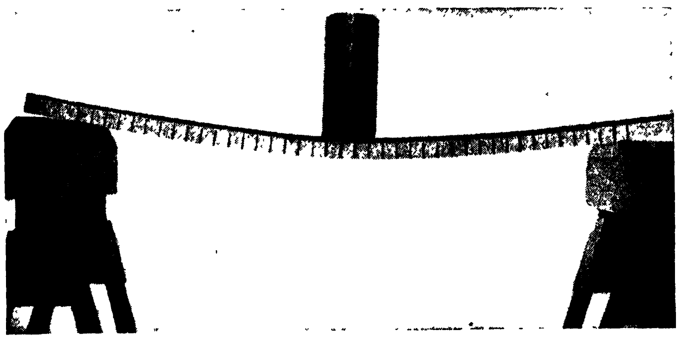


FIG. 111.

Place the notched beam on the pair of horses as shown and load enough weight on its midpoint to cause it to deflect. For this first case, allow the notches to open downward. Observe carefully the changes that the notches undergo in shape as the load is placed upon the beam.

Then answer the following questions on your paper, making a complete statement in answer to each:

1. As you watched the ends of the notches, did you notice any change? Make a sketch of the end view of one of the notches, showing its shape when the beam was loaded.
2. From your sketch, is the mouth of the notch wider or narrower than the root?

3. Taking the two opposite horizontal surfaces of the beam into account now, what does your answer to the previous question indicate regarding the comparative lengths of these two surfaces?
4. If a piece of material is being pulled on in such a way that its length tends to increase, it is commonly spoken of as being "in tension." Conversely, if the material is being squeezed so that the tendency is to reduce it in size, it is spoken of as being "in compression." Now, with reference to the previous question, tell whether the lower surface of the beam is in tension or in compression.
5. Does the above principle apply to the cantilever beam, as shown by Fig. 112?

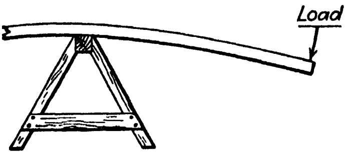


FIG. 112.

Now continue the experiment, this time reversing the notched beam so that the notches open upward. Place the same load on the midpoint of the beam, and observe carefully changes that the notches undergo if any.

Then answer the following questions:

6. As you watched the ends of the notches, did you notice any change? Make a sketch of the end view of one of the notches, showing its shape when the beam was loaded.
7. Referring to your answers to the former questions, is the upper surface of the beam in tension or compression?

General Conclusion: As your conclusion, make a general statement telling where tension and compression are found in a loaded beam. Make sure that your statement covers both the usual two-support beam, and the cantilever type.

Have you ever tried to break kindling wood over your knee, giving the piece of wood a sharp blow over that member? If you haven't, get a small piece of kindling wood from your instructor and try it. As the wood breaks, note whether the side that is in tension or the side that is in compression lets go first. Now, clamp one end of another piece of wood in a vise and break the wood by pushing steadily on the other end of it. Note whether the tension or the compression side of the wood gives way first.

8. Do the specimens break on the tension side or on the compression side?
9. Now make a statement telling what you found out about the comparative surface strengths of a beam in compression and in tension.

It must have occurred to you before now that the surface tension and compression in the same beam can vary greatly, due to its method of use. For instance, 2-in. × 8-in. beams are always used on edge as floor beams; they are never used for this purpose with the broad side facing up. The reason is apparent. Used flat side down, they bend considerably and act somewhat like a springboard. When used on edge, the beam remains practically rigid under heavy floor loads. Following is the rule that governs such cases of bending in beams. This rule is an approximate statement of a mathematical formula.

Rule: When a beam has a section such that a large number of outside fibers are massed at a remote position from the neutral axis, the surface tension and compression that the beam withstands

are divided between a large number of fibers. When the bulk of the fibers is massed near the neutral axis, while a very few are placed in a remote position, the opposite result is true; the stress would be divided among a very few fibers with the result that the beam would bend more easily.

Definition: The *neutral axis* of a beam is the axis which undergoes no change in length due to bending, and along which the direct stress is zero. The fibers on one side of the neutral axis are stressed in tension, and on the other side in compression.

From the foregoing discourse, you can readily see that a 2-in. × 8-in. beam on edge presents a great number of fibers at a remote position from the neutral axis, while a 2-in. × 8-in. beam on its flat side has all its fibers close to the neutral axis. Therefore, in accordance with the foregoing rule, the 2-in. × 8-in. on edge would not bend nearly so much as the beam on its flat side. Practice and theory coincide here.

The shape of the cross section, then, can and does control the amount that a beam will bend. You have just seen that a high rectangular cross section does not bend so easily as a flat rectangular section; in like manner, every different shape of cross section will react differently to bending stresses. The rule is the only method that you have whereby you may determine which section is really most suited to your particular needs, and it requires a bit of judgment in

estimating for the proper section. In any of your problems, then, you must exercise a little common-sense in making your choice.

UNIT 6. Illustrations of Surface Tension and Compression

1. Suppose that it were necessary for you to lead wire conduit or a pipe through a beam in the cellar of your house, as shown by Fig. 113, where would you bore the hole, at *A* or at *B*? Why?

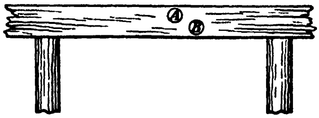


FIG. 113.

2. The following sketch is that of the cross section of a reinforced-concrete floor slab. Where should the reinforcing steel rods be placed, near the top surface, near the bottom surface, or halfway between? Explain. Which way should the rods run, crosswise or lengthwise? Why?

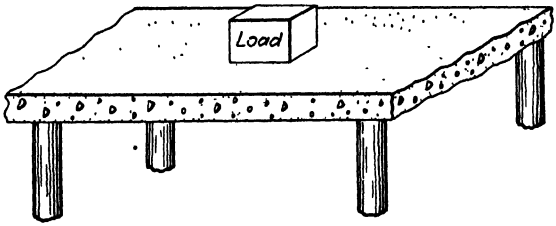


FIG. 114.

3. If you were putting up a cantilever-type balcony, to be made of concrete, reinforced internally with steel

rods, on which side of the centerline would you lay in most of the steel rods, above or below? Explain why.

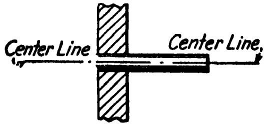


FIG. 115.

4. The sketches shown by the following figure are cross-sectional views of two different wooden cantilever beams. Which beam would you use, if the beam were supporting a heavy load at its outer end? Why?

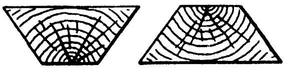


FIG. 116.

5. Figure 117 shows the cross-sectional view of a beam commonly known as an I beam. Show by a sketch how a horizontal I beam should be placed to support a downward load, when used as a simple beam (two supports). Explain why you think it should be used so.

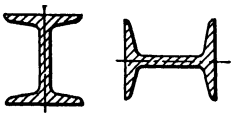


FIG. 117.

APPLICATIONS OF SURFACE TENSION AND COMPRESSION

Bring into class a written discussion of at least four other cases, from either your shop or your home, in which the principles of surface tension and compression are involved. Make a sketch of each case.

BLOCK V

ANGULAR FORCES

UNIT 1. Composition of Forces

If two forces are acting on a body, it is evident that they can act on it in only one of three ways, providing they are in the same plane.

Case 1. They can act in the same straight line in the same direction.

FIG. 118-*A*.

Case 2. They can act in the same straight line, but in opposite directions.

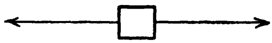


FIG. 118-*B*.

Case 3. They can act at an angle to each other. Forces of this type are called angular forces.

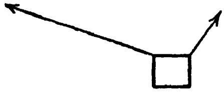


FIG. 118-*C*.

In Cases 1 and 2, the forces in question may easily be replaced by a single force, which will have the same effect on the body as the joint action of the two original forces.

Definition: A single force that can replace two or more other forces, so that the same objective is accomplished, is known as the *resultant force.*

In Case 1, if the two forces act in the same straight line and in the same direction, the resultant force is equal to their sum. In Case 2, the resultant force is equal to the difference of the two opposite forces.

The condition that presents itself is different, however, in the case of the two forces acting at an angle to each other. The resultant force in this case obviously can be neither the sum of the two forces nor their difference. Its direction is also unknown. Consequently, your task in the following experiment will be to investigate the possibility of a resultant of two forces acting at an angle to each other. You must also find out the magnitude of the resultant force and the direction taken by it.

EXPERIMENT

Place the box of bricks on the floor and hook up two 50-lb. scales as shown in the following figure. Get another

Fig. 118-*D*.

boy to help you, and have him pull on one scale while you pull on the other, in the meanwhile keeping a certain constant angle (neither too sharp nor too wide, about 45 deg.) between the two directions of pull. Pull together until the box starts to move, and while it is moving, note the scale readings. Pull parallel to the floor.

Now pull the box along the same path, this time using a single 50-lb. scale. Note the scale reading while the box is in motion.

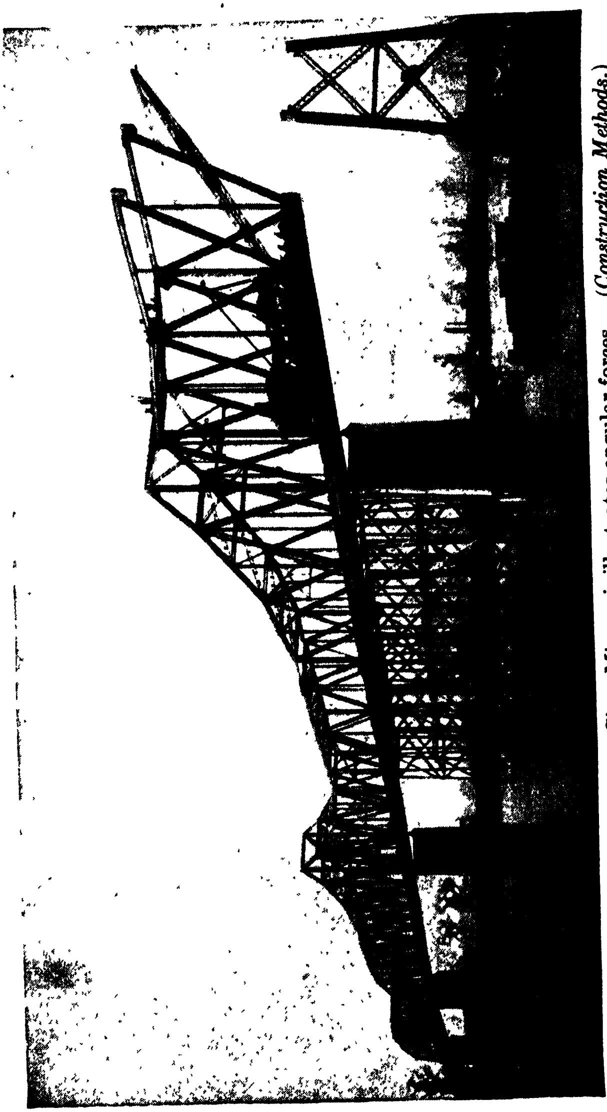
Answer the following question, making a complete statement:

1. Did the single-scale setup accomplish the same purpose as the double-scale setup?

General Conclusion: As your general conclusion, make a statement telling whether or not a single force called a resultant can replace two forces acting at an angle to each other.

As a point of information, the conclusion that a single force can replace two forces may be enlarged to accommodate the fact that a single force can replace many forces. Simply by substituting a single force for every two forces in a system of many forces immediately cuts in half the number of forces acting. Then by again substituting a single force for each of the remaining pairs of forces left, the system again reduces itself by one half. This method may be continued until the entire system condenses itself into one remaining force, called the *resultant.*

Now, *if* you have decided that you may replace two or more forces acting at an angle to each other by a single resultant force, your next job will be to find out



Missouri River Bridge, Kansas City, Missouri, illustrates angular forces. (*Construction Methods.*)

what it is that controls the direction and the magnitude of this resultant. There are several items that you might consider as control factors to experiment with, and the following are a few that you might begin to consider:

Item 1. The effect of changing the angle between the two forces.

Item 2. The effect of varying the forces while holding the angle constant.

If you have any other items to add to the list of probable control factors, do so, and experiment with all of them to determine which of the items listed are really control factors.

First, consider Item 1. If you are to find out whether or not the angle between the two forces has any effect on the magnitude of the resultant, everything else must be kept constant.

Using different angles between the forces pull the box along the floor. Remember to pull in the direction that your scale is pointing. In order to prevent the two scale readings from changing, it may be necessary to add or take out some of the bricks in the box. Following each indi-

DATA TABLE

Case No.	Size of angle	Scale reading of one force	Scale reading of other force	Scale reading of resultant
1	Small (about 15 deg.)			
2	Larger (about 100 deg.)	Same	Same	
3	Largest (about 160 deg.)	Same	Same	

FIG 119.

vidual test, in which you vary *only* the angle between the forces, hook a single scale onto the box of bricks and get a scale reading of the resultant force. Record all your observations in a data table similar to Fig. 119.

2. Since the two angular forces remained unchanged throughout the experiment while the angle between them was varied, make a statement telling what effect the variation in the angle had on the resultant force.

Control Factor: Make a statement telling whether or not the angle between angular forces controls the magnitude of the resultant force. Explain your statement.

Now consider Item 2. If you are to find out whether or not a variation in the forces, while retaining the same angle between the forces, has any effect on the direction of the resultant, setups as shown by the following figures will help you to an easy solution.

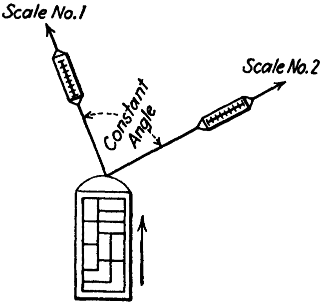


Fig. 120.

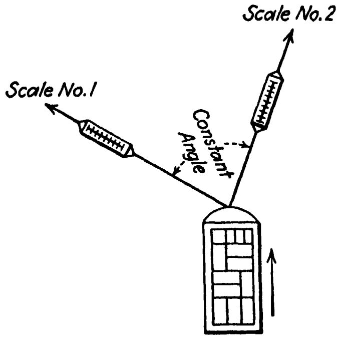


Fig. 121.

Pull the loaded box of bricks along the floor as shown, and record the scale readings of the forces. Note also the actual path taken by the box as it travels along, with regard to the directions taken by angular forces.

DATA TABLE

Case No.	Angle	Scale reading of force 1	Scale reading of force 2	Direction of resultant (nearest which force?)
1	Same			
2	Same			

FIG. 122.

Study your data table and answer the following question:

3. Explain what effect varying the magnitude of the angular forces had on the direction taken by the resultant. Does it follow more nearly the direction taken by the greater or the lesser force?

Control Factor: Make a statement telling whether or not the magnitudes of the angular forces control the direction taken by the resultant.

SUMMARY

Copy the following statements on your paper and fill in the words which make the statements true:

4. Two or more forces may be replaced by a single . . . .
5. By increasing the angle between two angular forces, the resultant automatically . . .
6. The direction of the resultant of two forces is determined by . . . .
7. The resultant of a pair of angular forces will always tend to follow the direction of the . . . . force.
8. If the resultant of a pair of angular forces remains constant while the angle between the forces increases, the magnitudes of the angular forces will . . . .

UNIT 2. Illustrations of the Composition of Forces

1. *a.* The following sketches illustrate two hanging electric lamp fixtures. Both lamps are of the same size and weight. From the sketches, tell which lamp will require the stronger wire to suspend it. Why?
   b. How can you tie up this fact with your experiment?

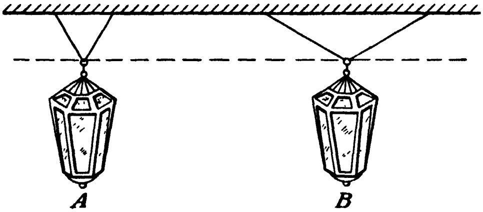


FIG. 123.

2. *a.* Tell from the following sketch of the traveling crane whether the beam AD is working under a tensile or a compressive stress. How do you know?
   b. If the angle between the two angular supports were reduced, would the beam AD stand more or less chance of failure under the stress that you named in the first part of the question? Explain.

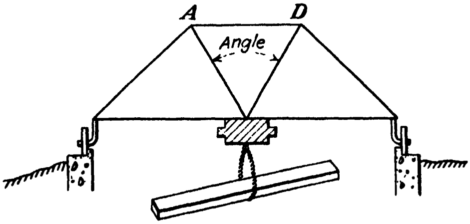


FIG. 124.

3. *a.* The following figure illustrates a cable system across a chasm. Which support is supporting the greater pull? How do you know?
   b. Can you tie up your answer to some control factor? Which one?

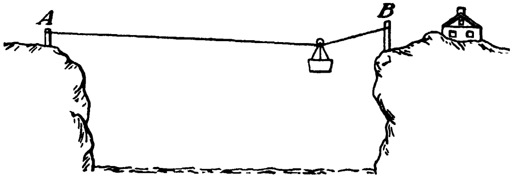


FIG. 125.

4. The sketch shown by Fig. 126 is that of a hoisting crane. If the crane is being used to lift scrap iron, and has a heavy electromagnet, the load end of which is raised and lowered by the cable, tell from the sketch whether the boom would have to stand more or less of a compressive stress if it were lengthened to twice the length shown. Explain your answer.

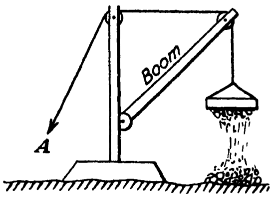


FIG. 126.

5. In building a water tank similar to the one shown by Fig. 127, how would it affect the strength of the whole structure, if the crossties on the bottom were increased to double their present length? Why?

6. Frequently, when the big electric-company truck hoists are lowering into the post holes the poles for carrying high-tension wires, a pair of men steady the pole by the use of a rope about the top as shown by Fig. 128. Assuming that the heavy pole began to tip away from them, would the men be more effective in preventing it by standing close together, or by separating? Which control factor does this tie up with?

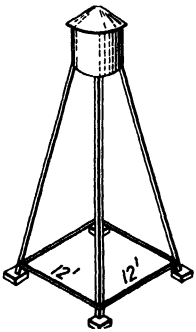


FIG. 127.

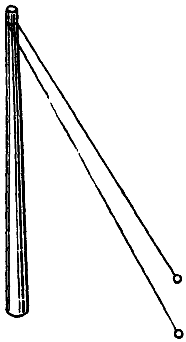


FIG. 128.

UNIT 3. Applications of the Composition of Forces

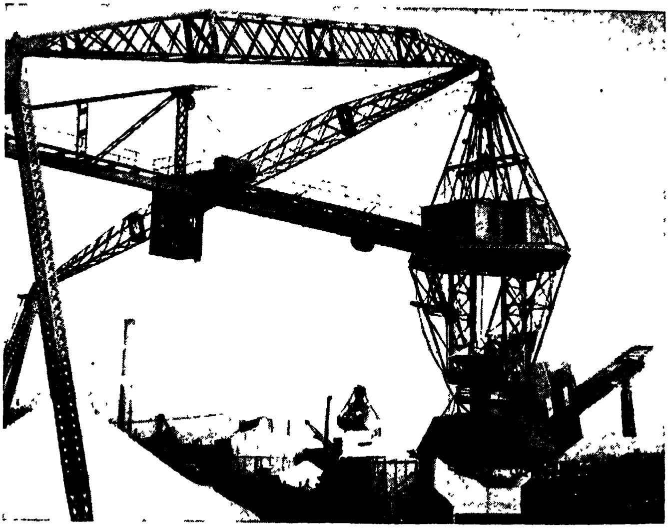
Bring in to class a written discussion *with sketches* of as many more cases (three at least) that you know of where angular forces are involved.

UNIT 4. Resolution of Forces

You remember, in the first unit, you determined that it was possible to replace angular forces acting on an object with a single resultant force. This method you called composition. The converse case, however, is the one to which this unit is devoted. The converse of composition is called *resolution.*

> **Definition:** The process of replacing a single force with two or more forces having the same joint effect as the original force is called *resolution* of forces.

It is unnecessary to repeat the previous experiment merely to illustrate the interchangeable feature between resolution and composition. It is quite obvious that, if two forces are replaced by one force, one force can be replaced by two forces. Stated as a general conclusion the fact for this unit reads: A single force may be replaced by two or more forces which accomplish the same purpose.



Traveling crane at Merrimac Chemical Company, Everett, Massachusetts, illustrates angular forces. (*Oilways.*)

The control factors are another question, however, since one resultant may have hundreds of different combinations of angular forces, depending on the angles between the forces. The direction taken by any of the angular forces depends entirely on the magnitudes of these forces; this is easily seen by reference to the statement made prior to this one. Stated as a control factor, the statement reads: The direction of angular forces is controlled by the magnitudes of the forces.

The magnitudes of the forces are, of course, controlled by the angles between them. Stated as a control factor, this statement reads: The angles between angular forces control their magnitudes.

Following is a group of illustrations which will serve to bring out the points discussed in the last few paragraphs. Explain each case in detail.

UNIT 5. Illustrations and Applications of Resolution of Forces

1. *a.* In splitting two similar tree trunks, two wedges having different slopes were tried, as shown by Fig. 129. Which wedge would exert the greater splitting force (the greater outward force)? Why? Assume that the same blow is struck on the butt of each wedge.

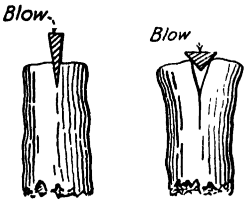


FIG. 129.

   b. With which control factor does this fact tally?

2. *a.* Figure 130 represents a pair of sawhorses. If the same load is applied to each horse, tell from the sketches which horse is more liable to collapse as the load increases. Why?

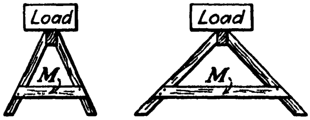


FIG. 130.

   b. What stress is present in the cross member M? Which horse is resisting the greater stress in the cross member? How do you know?

3. *a.* Explain what effect a train crossing the bridge truss shown in Fig. 131 would have on the stress in the two cross members A and B, if the angle between them were increased.

b. To which control factor does this fact tie up?

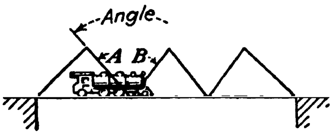
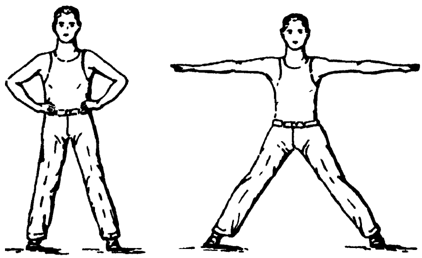


FIG. 131.

4. Which position, *A* or *B*, requires more strength in your legs, if you are to maintain the position for any great length of time? (See Fig. 132.) Explain why in terms of your control factors.



A *B*

FIG. 132.

5. The two pistons *A* and *B* in the following figure receive their force from the action of the cam and the crosshead slide. As the cam rotates in the direction shown, the crosshead is forced down, thereby transmitting its force to the two pistons. If the angle be tween the two pistons were increased, would the pistons *A* and *B* exert more or less force? Explain your answer.

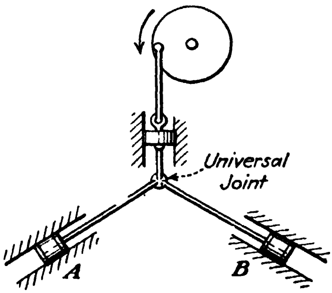


FIG. 133.

6. *a.* Figure 134 is that of a smokestack guyed down with strong wires. If the section of the country where the stack is located frequently has high winds, would it be advisable to bring the lower ends of the guy wires in closer to the base of the stack? Why?
   b. To which control factor does this fact tie up?

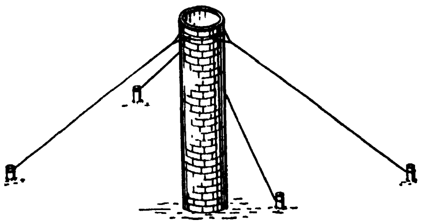


FIG. 134.

7. Locate as many more applications (three at least) of the principle involved in this unit; that of replacing a single force by components, and describe them briefly. Make a sketch of each case.

BLOCK VI

PROPERTIES OF MATERIALS

UNIT 1. Tension

In the industrial world, by far the great majority of commercial specifications, in so far as they are concerned with the properties of the material, are based on tensile tests. That is to say, most structural and industrial materials are rated as having a certain tensile strength, that being their most important factor.

Definition: *Tensile strength* is the measure of the ability of a substance to withstand a pull.

The brake rods on an automobile are constantly being subjected to pulls or tensile stresses, the chain hoists in the shops must withstand certain tensile stresses, the belts that turn industry's wheels must withstand tensile stresses, even the threads that make up the clothes that you wear depend on their tensile strength to make your clothes resistant to tearing.

In the experiment which you are to do, several materials will be tested in order that you may observe the comparative amounts of tension that they are able to withstand before breaking. Figure 135 is an illustration of the apparatus which you are to use.

Note that the strips of material to be tested are fixed at both ends of the apparatus and that they are subjected to a tensile stress by pulling on the lever handle as shown.

EXPERIMENT

First, try the pull on the lever necessary to break a strip of newspaper 1 in. wide and about 24 in. long. Compare this pull with the pull necessary to break a strip of tracing paper, also 1 in. wide and 24 in. long. Then, compare with these pulls the amount of force necessary to break similar pieces of regular bond paper and thin sheet metal.

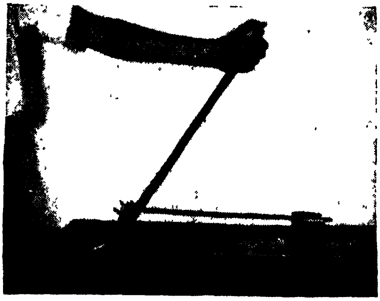


FIG. 135.

Remember, only a steady pull will give you good results. Do not use a sudden surge of force on the lever handle while experimenting. If you wish to check your results, hook a scale on the lever handle and compare readings. Record in a data table, similar to the one shown by Fig. 136, the pull that was required to break each of the materials. Use the usual terms such as, "the least," "the most," "less," "more," etc., to denote changes in the amount of pull.

DATA TABLE
Different Materials

Material	Width	Thickness	Force needed to break	Ability to resist tension
Newspaper	1 in.	Very thin		
Tracing paper	1 in.	Very thin		
Bond paper	1 in.	Very thin		
Sheet metal	1 in.	Very thin		

FIG. 136.

Study the results in your data table. Then answer the following questions, making a complete statement in answer to each:

1. Did you feel any variation in the amounts of pull required to break the materials tested?
2. Would a variation in the amounts of pull required indicate a difference in the tensile strength of the material?

General Conclusion: What conclusion have you arrived at regarding the comparative tensile strengths of different materials? State your answer as the general conclusion.

For investigating the possible control factors for tension, it is suggested that you consider the following items.

Item 1. The effect of varying the width.
Item 2. The effect of varying the thickness.
Item 3. The effect of varying the length.

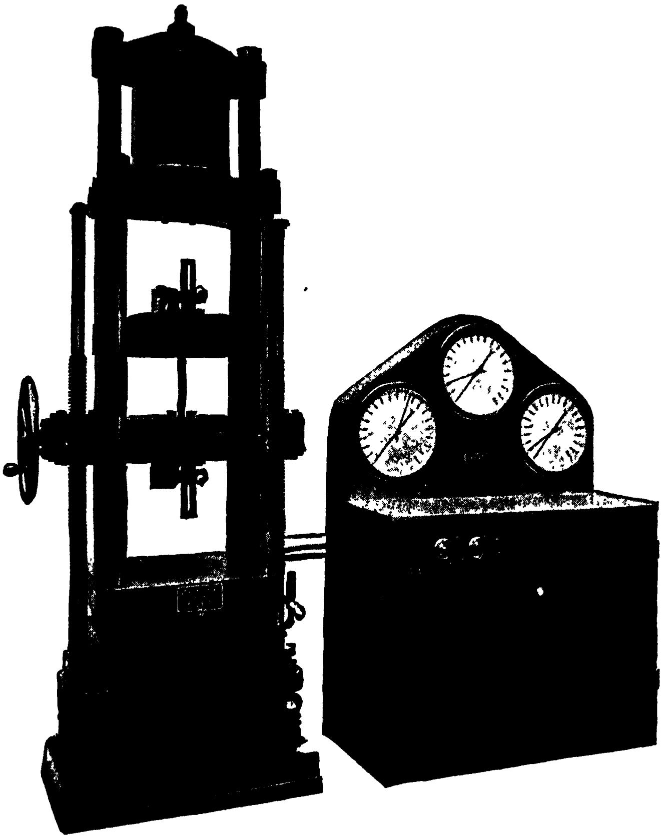
Remember, in determining whether or not any one item is a control factor, all other items must be kept constant.

The following table may be used as a guide for your experiment with the first item.

DATA TABLE
Different Thicknesses

Material	Number of thicknesses	Force required to break	Ability to resist tension
Newspaper 1 in. wide	One		
Same	Two		
Same	Four		

FIG. 137



Machine for testing tensile strength. (*Tinius Olsen Testing Machine Company.*)

Try to break the materials indicated in the table, using the same apparatus as you did for the first part of the experiment, and record your results in the data table.

Study your results; then answer the following questions:

3. Did you feel any variation in the amounts of pull required to break the material, as the thickness varied? Explain.
4. Would a variation in the pull indicate that the thickness was controlling the amount of pull required?

Control Factor: Is the thickness a control factor of tension? Make your answer in the form of a complete statement.

In the same manner that a change in thickness was tested, find out how variation of the width of a material affects its ability to withstand tension. Use the following table as a guide.

DATA TABLE
Different Widths

Material	Width	Force required to break	Ability to resist tension
Bond paper single thickness	½ in.		
Same	1 in.		
Same	2 in.		

FIG. 138.

Study your results; then answer the following questions:

5. Did you feel any variation in the amounts of pull required to break the material as the width varied? Explain.
6. Would a variation in the pull indicate that the width was controlling the amount of pull required?

Control Factor: Is the width a control factor of tension? Make your answer in the form of a complete statement.

Now vary the length and note any change in the tension that occurs. Use the following table as a guide.

DATA TABLE
Different Lengths

Material	Length	Force required to break	Ability to resist tension
Newspaper 1 in. wide	6 in.		
Same	12 in.		
Same	18 in.		

FIG. 139.

Study your results; then answer the following questions:

7. Did you feel any variation in the amounts of pull required to break the material as the length varied? Explain.
8. Would a variation in the pull indicate that the length was controlling the amount of pull required?

Control Factor: Is the length a control factor of tension? Make your answer in the form of a complete statement.

9. You have investigated width and thickness separately as control factors for tensile strength. It is desirable to have a combined statement covering the two cases. Try to fill in the missing words in the following statements:
   a. If you multiply the width of a rectangular cross section by its thickness, you get its . . . .
   b. The tensile strength of any material varies as the . . . . of its cross section.

SUMMARY

Copy the following statements on your paper and fill in the words which make the statement true:

10. By reducing the thickness of a piece of material, the resistance that it offers to tensile stresses becomes . . . .

11. Varying the length of a piece of material . . . . its resistance to tensile stresses.

12. The resistance that a material having a certain, constant thickness has to tensile stresses may be increased by increasing its . . . . .

UNIT 2. Illustrations of Tension

1. *a.* Compare the tensile strength of a piece of wood 1 in. wide and 1/8 in. thick with that of a piece of the same wood having a cross section of 1 in. × 1 in. Which offers the more resistance to tensile stresses?

b. To which control factor can you tie up your answer?

2. *a.* Compare the tensile strength of a piece of round steel 1/2 in. in diameter with that of another piece of the same kind of material but having a diameter of 1 in.

b. To which control factor can you tie up your answer?

3. The ropes on a swinging scaffold, rigged up to paint a two-story building, were changed by the painter to ropes of much larger diameter, when the scaffolding was rigged up for painting a six-story building. Did the painter know very much about tensile strength? What was wrong with his reasoning? Explain your answer in terms of something you learned in your experiment.

4. A piece of leather 1/8 in. × 1/2 in. is harder to break by pulling on it than is a piece of wood having the same cross section. With which principle in the experiment does this fact tie up?

5. If a man driving a car pushes down too hard on a brake pedal, and in so doing breaks the rod operating the brakes,

what is it that really happens at the point of breaking? Would making the brake rod longer have helped any? Why? How would *you* have remedied the trouble?

6. Two pieces of the same material are in tension. One piece has a square cross section, while the other piece has a rectangular cross section. Both pieces are equal in cross-section area, however. Which piece will break more easily? Why?
7. Two pieces of the same material are in tension. One piece has a square cross section, while the other piece has a circular cross section. Both pieces are equal in cross-section area, however. Which piece will break more easily? Why?
8. Assume that a motor was driving a machine by means of a belt, and the belt snapped due to an excessive pull on it. Would it be a good idea to move the motor farther away from the machine and use a longer belt? Why? Explain what *you* would do to remedy the trouble.
9. Make a sketch of a cross section of a rectangular beam 6 ft. 0 in. long, $\frac{1}{2}$ in. thick and $1\frac{1}{4}$ in. wide. Compare its tensile strength with a beam of the same material that is 10 ft. 6 in. long, 1 in. thick and $2\frac{1}{8}$ in. wide. How many times more effective is one beam than the other in its ability to resist tension?

UNIT 3. Applications of Tension

There are many more cases where the tensile strength of a material or of a tool plays an important part, similar to those listed under Illustrations.

List at least six cases where the principles of tension are involved, and explain each in detail. It would be well to make a pencil sketch of each case.

These applications should be brought in from your contacts in everyday life and in the shop. Look around in your shop and your home for these applications, list them on your paper, and write them up in the science class room.

UNIT 4. Compression

In your shop and in your home life you see many cases of what you are now to call *compression*. The roadway that you ride on is constantly being subjected to compressive forces, or stresses as they are called by engineers; under the wheels of traffic; the legs of the chair that you sit on, even the rubber heels that you walk on are obliged to withstand certain compressive stresses.

Definition: The *compressive strength* of a material is the measure of its ability to withstand being pressed or squeezed together.

The list of things that are constantly withstanding compression in your regular home and shop life is infinite; everywhere you go and in many things that you do, you will find compressive stresses. Even the graphite in your pencil is compressed as you write.

The following experiment is designed to give you the opportunity to study the action of compressive forces on materials, in order that you may observe the comparative amounts of compression that they are able to withstand.

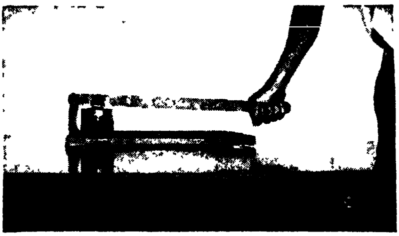


Fig. 140.

EXPERIMENT

The apparatus illustrated by Fig. 140 is that which you are to use in your experiment. Note that the materials to be tested are placed on the base, exactly upon the center of the anvil, and they are subjected to a compressive force by pushing down on the end of the lever handle. Only a steady, even push will give you the results that you want. Do not use a sudden jolt on the handle.

Try the amount of force necessary on the end of the lever to crush a piece of soft lead that is in the shape of a ¼-in. cube.

Compare the amount of force necessary to crush the lead with the amount of force necessary to crush a piece of common chalk, also in the shape of a ¼-in. cube.

Compare with both of the foregoing forces the amount of force necessary to crush a ¼-in. cube of paraffin.

Record in the data table the amount of force required to crush each of the three foregoing materials. Make use of

the usual terms for expressing the comparative amounts of compression.

The following data table is the type that you should use for recording the results of your test.

DATA TABLE
Different Materials

Material	Size	Amount of force needed to crush	Ability to withstand compressive stresses
Soft lead	¼-in. cube		
Chalk	¼-in. cube		
Paraffin	¼-in. cube		

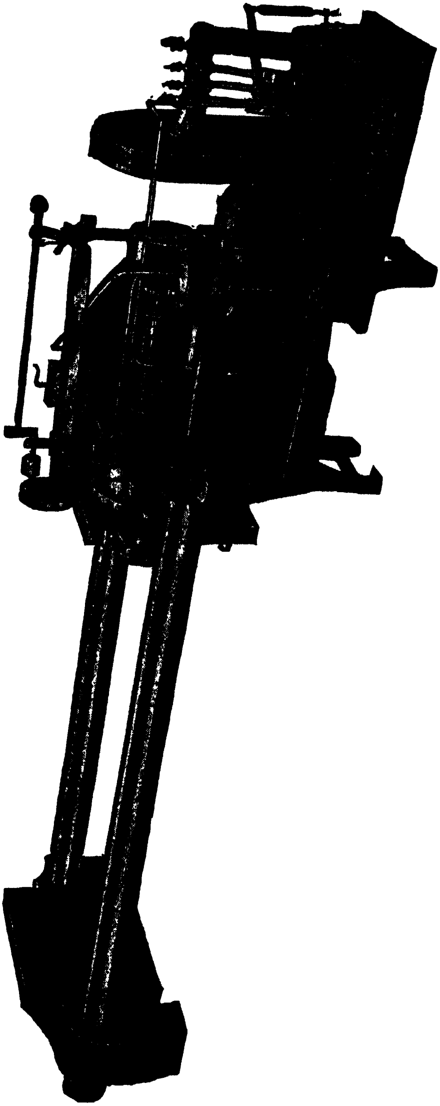
FIG. 141.

Study your data table carefully. Then answer the following questions on your paper, making a complete statement in answer to each:

1. Did you feel any difference in the comparative amounts of force necessary to crush each of the materials?
2. Would differences in the amounts of force required to crush the materials indicate differences in the ability of each material to withstand compressive stresses?
3. Does the last column of the data table agree with your answer to Question 2?

General Conclusion: As your conclusion, make a general statement, covering all cases, in which you state the behavior of materials of different kinds when subjected to a compressive stress.

Your next obligation is to find the factors that control the amount of crushing force that a material is able to resist. To start with, consider what effect the thickness and the cross-sectional area have on the ability of the substance to resist these compressive stresses.



Machine for testing compressive strength. (*Tinius Olsen Testing Machine Company.*)

Remember, in order to determine whether any one item is a control factor, all other factors must remain constant. Use the following data table as your guide in experimenting and comparing the resistance that a substance offers to compressive stresses when only the cross-sectional area[1] in a plane perpendicular to the direction of the stress is varied.

Try to crush on the compression machine the materials indicated in the data table. Record your observations in the data table in the usual manner.

By double area it is meant that two pieces of the material having the same shape and size are placed side by side on the anvil and under pressure.

DATA TABLE
Different Areas

Material	Amount of area	Amount of force required to crush	Ability to withstand compressive stresses
Chalk	Single		
	Double		
	Triple		
	Quadruple		

FIG. 142.

After completing the data for the table, examine your results carefully. Then answer the following questions, making a complete statement in answer to each:

4. Did you feel any difference in the comparative amounts of force necessary to crush the material when the area was doubled, tripled, or quadrupled, as compared with the force necessary to crush the single original area?
5. Would a difference in the required force indicate that the area under pressure had a direct influence on the resistance that the material had to compressive stresses?

[1] See Unit 1 of Block VI for reference on *cross-sectional area.*

Control Factor: Make a statement, now, telling whether or not the cross-sectional area of the material under a compressive stress can control the ability of the material to resist the stress.

Now experiment with pieces of the same material in order to determine whether or not thickness is a control factor. Follow the same method in testing that you have been accustomed to.

Use the following table as your guide in experimenting, and record the usual terms to denote changes in the amount of force necessary to crush the materials.

When testing double and triple thicknesses of the material, simply place one piece of material on top of the other, thereby doubling or tripling the height.

DATA TABLE
Different Thicknesses

Material	Thickness	Amount of force needed to crush	Ability to resist compressive stresses
Chalk	Single		
	Double		
	Triple		

FIG. 143.

After completing the data for the table, study your results carefully. Then answer the following questions, making a complete statement in answer to each:

6. Did you feel any difference in the amounts of force necessary to crush the material when the thickness was doubled or tripled, as compared with the single original thickness?
7. Can you say that the thickness of the material under pressure controlled the resistance of that material under the compressive stress?

Control Factor: Make a statement, now, telling whether or not the thickness of the material under a compressive stress can control the ability of the material to resist the stress.

If you have any other items that you would like to experiment with, in order to determine whether or not they are control factors, do so, and make a complete data table for each item.

SUMMARY

Copy the following statements on your paper, and fill in the words that make the statements true:

8. The greater the cross-sectional area of a material, the . . . will be its resistance to compressive stresses.
9. By increasing the thickness of a material, its resistance to compressive stresses .

UNIT 5. Illustrations of Compression

1. Compare the compressive strength of a block of concrete 5 ft. long by 2 ft. wide, with a similar block of concrete whose width is only 1 ft. and whose length is 5 ft. How many times stronger is one than the other? Why?
2. Compare the compressive strength of a round wooden column 2 ft. in diameter with a similar column of wood 4 ft. in diameter. How many times stronger is one than the other? (The areas of two circular sections are to each other as the squares of their diameters.) Explain your answer.
3. A block of pine wood, used as a support under a certain part of a punch press became partly crushed after having

received repeated shocks and was replaced by a cast-iron base. Would the cast iron stand up under the shocks any better than the pine? Why?

4. Two pieces of the same material are in compression. One piece has a square cross section, while the other piece has a rectangular cross section. The cross-sectional areas of both pieces are equal, however. Which piece will crush more easily? Explain in terms of your experiment.
5. Explain in terms of the principles that you studied in your experiment why rubber heels are sometimes put on footwear instead of leather heels.
6. Explain in terms of your experiment which is better to use as a bearing plate under the end of a steel girder, a slab of oak or a steel plate.
7. *a.* Sometimes a ball or roller bearing will be crushed under a heavy load. In which two important ways could you remedy this fault?

   b. To which factors can you tie up your answers?
8. *a.* If you built a platform that was supported by four round granite columns and you decided that you would like to be able to support more weight on the platform than you had originally designed it for, would it be of any use to shorten the length of the supporting columns if the platform has been previously loaded to the crushing point of the granite columns?

   b. Would it help to add more supporting columns? Explain in terms of your experiment.

UNIT 6. Applications of Compression

Discuss in detail, and draw sketches of at least four other cases that you know of where you have seen a com-

pressive stress at work. Shop applications of this sort are usually plentiful.

UNIT 7. Buckling

If you have ever tried to compress a piece of tin, as shown by the diagram below, you know what the real action of buckling is in a material.

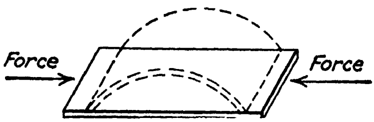


FIG. 144.

When pressure is applied at the ends of the piece of tin, it usually springs the material out of shape as shown by the dotted lines. This tendency to spring is known as *buckling*.

Definition: *Buckling* is the tendency for materials to spring out of shape when subjected to a compressive stress.

Buckling is really a very common thing in everyday life; *i.e.*; if the vertical beams that hold up the house that you live in were not properly selected, they might buckle and cause damage; the piston rod of an automobile engine must be so constructed that it is able to resist buckling under continuous endwise

pressure. Knowing, then, that buckling is of importance in several ways, you are now going to investigate buckling and determine the factors that control it.

EXPERIMENT

The following sketch illustrates the apparatus to be used in testing materials for buckling. You will note that the piece of material to be tested is placed vertically in the apparatus and allowed to protrude through the upper slot about ½ in. The upper block with the slot is adjustable and its height above the base may be changed by resetting the wing nuts on the back of the apparatus.

Fig. 145.

First, test a piece of pine wood 36 in. long, 1½ in. wide and ⅛ in. thick. Place it in the apparatus as shown in the sketch. Tighten the clamps that bind the bottom of the test piece, but *do not* tighten the clamp in the upper slot to the extent that the test piece will not be able to slide in the slot. Simply draw the clamp up enough to prevent the test piece from slipping around in the slot. Now, squeeze the two upper blocks vertically with your hands, using just enough force to buckle the specimen, and thereby bringing the weight table and the upper slotted piece together.

Repeat your experiment, using two other kinds of material, three-ply wood and a piece of steel. For the

steel piece, use a 36 in. steel scale. Record your observations in the data table in the usual manner. It is suggested that you use such terms as "the least," "the most," "less," "even less," "even more," etc. The following data table is the type that you should use in your experiment.

DATA TABLE
Different Materials

Material	Size	Amount of force required to buckle	Ability to resist buckling
Pine	36 in. × $1\frac{1}{2}$ in. × $\frac{1}{8}$ in.		
Plywood	36 in. × $1\frac{1}{2}$ in. × $\frac{1}{8}$ in.		
Steel	36 in. × $1\frac{1}{2}$ in. × $\frac{1}{8}$ in.		

FIG. 146.

Examine your data table carefully. Then answer the following questions, making a complete statement in answer to each:

1. Did you observe any variation in the amounts of force required to buckle the three different kinds of material?
2. Would a variation in the amounts of force required to buckle the materials indicate differences in their abilities to withstand buckling?
3. Does the last column of your data table agree with your answer to Question 2?

General Conclusion: As your conclusion, make a general statement regarding the behavior of different kinds of materials with regard to buckling, when those materials are subjected to compressive stresses.

Following is a list of a few items that might be considered as control factors. Experiment with each individual item and record your observations in

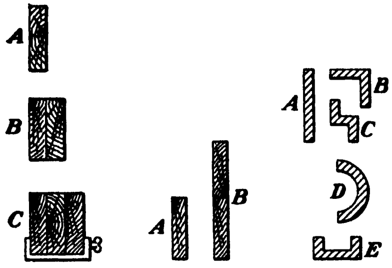
separate data tables. Add any other control factors to the list that you care to.

Item 1. The length of the test piece.

Adjust the wing nuts in back of the apparatus to accommodate three different lengths of pine wood, 36 in., 24 in., and 12 in. Test each piece and record the data in the usual manner in the data table.

Item 2. The thickness of the test piece.

Using 36-in. lengths of pine, make tests in which the thickness alone varies. First, use one piece alone, then two pieces, and for the last case, use three pieces of pine.



(a) (b) (c)

FIG. 146-*A*.

It may be necessary to use a small clamp on the test pieces to prevent them from bowing. Record all the data in the usual manner.

Item 3. The width of the test piece.

Using 36-in. lengths of pine, make tests in which the width of the material increases. Use a single piece first, then two pieces. Record all the data in a table.

Now answer the next three questions for each of the foregoing items, individually, making in all nine complete answers.

4. Did you observe any difference in the ability of the material to resist buckling, in the three cases of the factor in question?
5. Can you say, then, that the factor under consideration had a decided effect on the amount that the material buckled?

Control Factor: Then would the item be a control factor? If so, state it as such on your paper.

10. Is the cross-sectional area of the material you tested a control factor? If so, on what do you base your claims?

Item 4. The shape of the cross section.

Using 36-in. lengths of galvanized iron, each piece 3 in. wide to begin with, bend (or have your instructor procure some pieces already bent) the metal into shapes as shown by Fig. 146-*C*. Try to buckle each shape in the usual manner, and record your data in a table.

Answer the following questions, making a complete statement in answer to each:

11. Did you feel any difference in the ability of the material to resist buckling in the five different shapes of cross section?

Control Factor: Is the shape of the cross section of a material a control factor? (Cross section being at right angles to the direction of the force.) If so, state your answer as a control factor.

In a previous discussion on shapes of cross sections in the unit entitled "Surface Tension and Compression," Block IV, you learned that the beam that had the most number of fibers in tension and compression at the greatest distance from the neutral axis, would possess the greatest ability to resist bending. See if

you can connect this fact to the buckling experiment, and in so doing determine the approximate order in which the shapes you used should have buckled.

12. List the five experimental shapes in their order of buckling resistance. Do your answers check with the results of your experiment?

SUMMARY

Copy the following statements on your paper. Then fill in the words which make the statements true.

13. When the cross-sectional area of a certain beam is increased, the general shape remaining the same, the resistance that the beam offers to buckling is . . . .
14. The resistance that a beam with a rectangular-shaped cross section offers to buckling may be ... by ..... the shape.
15. The shape and the .... are factors that control the resistance that a material has to buckling stresses.

UNIT 8. Illustrations of Buckling

1. Regular steel, ¼ in. in diameter can very easily stand the compression that the weight of an ordinary table top causes. Could steel of this sort (¼ in. in diameter) be used for regular table legs? Would the length of the legs be an important item to consider? Why?
2. Explain what the purpose of the bridging is between the studs, as shown in the following sketch.

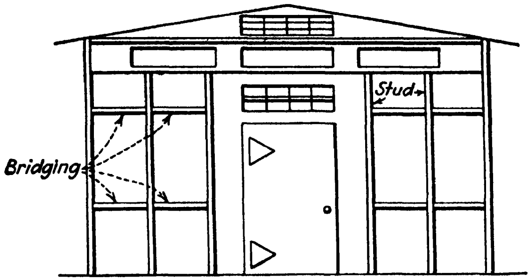


Fig. 147.

3. Explain how the principle of buckling applies to:

a. A small drill in a drill press that is being fed into the work too rapidly, and with too much pressure on the handwheel.

b. The steel legs of a water tower that are braced by cross members.

c. A long thin nail being driven into some hard wood.

Make a sketch of each case, and explain it in detail, with reference to your experiment whenever possible.

4. Chair legs are sometimes made of angle iron. Explain the reason why it is more practical to use angle iron, for this purpose, rather than flat rectangular stock of the same cross-sectional area.

5. The following sketch is that of a Z bar, a shaped beam commonly used in structural work. Its neutral axes

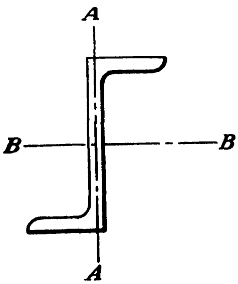


Fig. 148.

are AA and BB. With which axis as its neutral axis is this beam most likely to buckle? Why?

6. The following sketches illustrate the cross sections of an I beam and of a solid square beam, both having the same areas. Which section is the weaker under a buckling stress? Why?

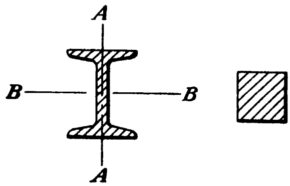


Fig. 149.

7. Examine the previous sketch of the I beam. With which axis (AA or BB) as its neutral axis is this beam most likely to buckle? Why?

UNIT 9. Applications of Buckling

Find at least four other cases in your own shop or your everyday life wherein the principles of buckling are involved. Make a sketch of each case and discuss it in detail on your paper.

UNIT 10. Torsion

In nearly every trade, there are many very obvious cases where torsion in materials is an important point

entering into the consideration. The automobile mechanics have a shining example of its importance in the automobile rear-axle shaft, that has been twisted off, due to an excessive stress.

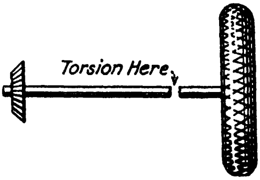


FIG. 150.

This is an extreme case of torsion. There are other times when this type of stress is not so violent, as in the case of shafts transmitting power by means of overhead shafting. Power from the driving unit is usually transmitted to the shafts by belts, and the shafts then transmit the power to the machines and tools where the desired work is to be performed. The shafts transmitting the power are being subjected to a constant twisting force, commonly called torsion.

Definition: When a material is subjected to a turning or twisting force, the material is said to be under a *torsional stress*.

In the experiment which you are to perform you will investigate and study the ability of different materials to withstand torsional stresses, and determine what the factors are that control torsion.

EXPERIMENT

Following is a sketch of the apparatus that you will use. Note that the test specimen is tightly clamped in the stationary block and allowed to rest in the U slot of the movable block.

Since your first objective is to observe the action of torsional stresses on several different kinds of material,

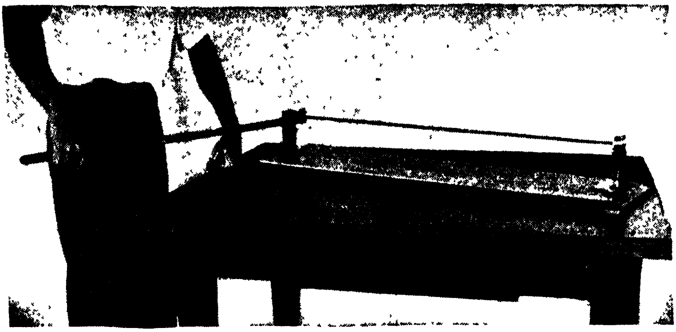


FIG. 151.

the following materials have been provided for your first test:

1. A $\frac{1}{4}$-in-diameter wood dowel, 24 in. long
2. A $\frac{1}{4}$-in.-diameter piece of steel, 24 in. long
3. A $\frac{1}{4}$-in.-diameter piece of brass, 24 in. long

Place the 24-in. $\times$ $\frac{1}{4}$-in. wood dowel in the stationary block, clamp it tightly; then adjust the movable block to accommodate the 24-in. length. Next, attach the lever handle to the test piece by clamping it tightly about $\frac{1}{16}$ in. away from the free support on the inside. Now, try the amount of force that is necessary to twist the dowel about 30 deg. Record your observations in a data table similar to the one following. Use the usual terms; *i.e.* "the least," "the most," "even more," "even less," "very little," "all I could pull," etc. As a check on yourself, to see if your observations have been made correctly, hook a scale through the hole in the end of the big bar and see how much force it takes to twist the specimen. Then, as an added point of interest, make a straight chalk or pencil line along the entire length of the piece when the specimen is twisted. Repeat the experiment

using the piece of steel and then the piece of brass. Record your observations for each case. (The test pieces must be of equal lengths and of equal cross sections.)

DATA TABLE
Different Materials

Case No.	Kind of material	Amount of force necessary to twist	Ability to resist torsion
1	Wood		
2	Steel		
3	Brass		

FIG. 152.

Study your data table carefully. Then answer the following questions, making a complete statement in answer to each:

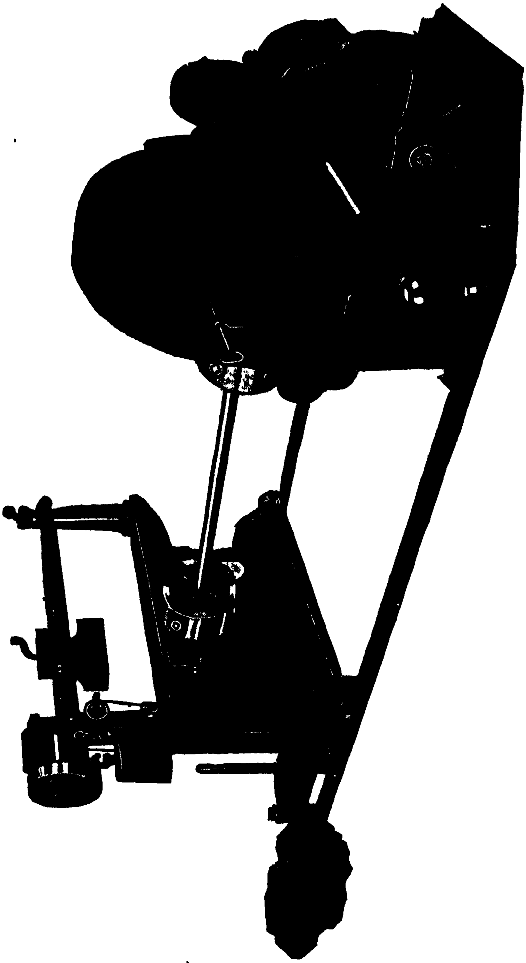
1. Did you observe any variation in the amounts of force necessary to twist the three materials the required 30 deg.?
2. Would differences in the amounts of force that the materials required indicate differences in their ability to resist torsion?
3. Does the last column in your data table agree with your answer to Question 2?

General Conclusion: As your general conclusion, make a statement telling definitely what the behavior is of different materials, with regard to torsion, when subjected to twisting loads.

Following are a few of the items that might be considered as control factors. Experiment with each individual item and record your observations in separate data tables. Add to the list any other control factors that you wish.

Item 1. The length of the test piece.

Adjust the movable block of the apparatus to accommodate three different lengths of ¼-in. steel rod, 36 in.,



Torsion testing machine. *(Tinius Olsen Testing Machine Company.)*

24 in. and 12 in. Test each piece for the amount of effort required to twist it about 30 deg. and record the data in the usual manner in a data table.

Item 2. The cross-sectional area of the piece.

Using 36-in. lengths of steel rod, make torsional tests in which the cross-sectional area of the test piece is the variable.

Use a piece of 1/8-in. diameter first, then a piece of 1/4-in. diameter, and last a piece of 3/8-in. diameter. Record all the data in a data table.

Answer the following questions for each of the items, individually, making a complete statement in answer to each.

4. Did you observe any difference in the ability of the material to resist torsion in the three cases of the factor in question?
5. Can you say, then, that the factor under consideration had a decided effect on the amount of resistance that the material offered to torsion?

Control Factor: Then, would that item be a control factor? If so, state it as such on your paper.

It is interesting to note that a solid square cross section, and a solid oblong section of a beam, having the same material and area, will differ considerably in their ability to withstand torsion. The same is true of two specimens of the same material and area, one having a solid square and the other a solid circular cross section. In the first case, the oblong section will fail under torsional stresses before the square, while in the second case the square section will fail before the round piece.

The rule that governs the above condition is as follows.

Rule: When a beam has a section such that a large number of outside fibers are massed at a remote position from the neutral axis (the neutral axis is the innermost fiber of the beam that is not being twisted or subjected to any stress) the torsion that the beam withstands is divided between a large number of fibers. When the bulk of the fibers is massed near the neutral axis, while a very few are placed in a remote position, the opposite result is true; the stress would be divided among a very few fibers, with the result that the beam would twist more easily.

Returning now to the subject of the shape of a cross section, it is easily seen that the circular cross section is the one figure that has the greatest number of its fibers at the greatest possible distance from the neutral axis and is, therefore, strongest in the ability to withstand torsional stresses.

If, however, you take the solid circular cross section and change it to a hollow circular cross section, having the same area, the resistance that a beam of this sort offers to torsional stresses is even greater. Referring to the foregoing rule for the proof of this fact, you find that the hollow circular cross section has a far greater resistance to torsional stresses simply because it has a greater number of its fibers at a greater distance from the neutral axis; consequently the torsional stresses are divided among more fibers.

The resistance that any one section offers to torsional stresses, as compared with the resistance offered to

similar stresses by another different section, can be very well approximated by the use of the foregoing rule, in the same manner as the preceding illustrative example.

SUMMARY

Copy the following statements on your own paper, and fill in the words which make the statements true:

8. A shaft whose cross section is . . . . has more resistance to torsional stresses than another shaft having the same area but whose section is octagonal.

9. . . . . . the length of a piece of material increases its resistance to torsional stresses.

10. . . . . the cross-sectional area of a material increases its resistance to torsional stresses.

11. Different materials whose cross sections are the same, ... withstand the same torsional stresses.

12. The control factors for any material being subjected to torsional stresses are: (Make a list.)

UNIT 11. Illustrations of Torsion

1. *a.* Would it be wise to mount a pulley, subject to extreme sudden loads, on a shaft that was hung between two bearings 40 ft. apart as shown by Fig. 153? Explain your answer in terms of torsion and its control factors.

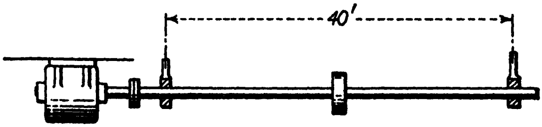


Fig. 153.

b. If, however, it was necessary to mount the pulley as shown in the sketch, due to local conditions, would it increase the ability of the shaft to transmit power more steadily if the shaft size were doubled? Why?

2. *a*. Figure 154 is an illustration of a foot pedal operating a drawrod by means of a shaft. Do you think that a setup like this is mechanically correct, if the work required of the attachment makes it necessary to use considerable pressure on the pedal? Explain your answer.

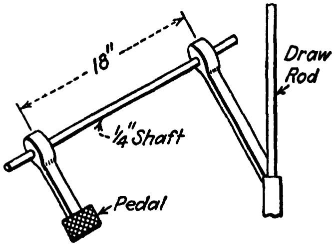


Fig. 154.

b. How would you rearrange or reconstruct the apparatus in order to do the same job in a way that is more mechanically correct?

3. Explain in terms of your experiment what actually happens inside a drill when it breaks while engaged in work. How can such a condition be remedied to a certain extent?

4. Explain in terms of torsion and its control factors why we don't use pure copper crankshafts in our automobiles?

5. *a*. Many times when screwing a brass wood screw into a piece of hard wood, the head of the screw twists off entirely. Explain this in terms of your experiment.

b. If the screw had been made of hardened steel, would it have made any difference in the torsion that it would have been able to stand before breaking? To what fact can you tie up your answer?

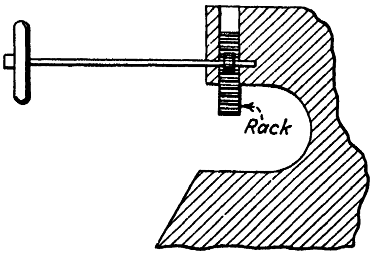


Fig. 155.

6. *a*. Figure 155 represents a small pinion gear operating

a rack in an arbor press. Study the sketch. What would you say was wrong with the design of the machine?

b. In what ways could you improve the design of the press? Upon what facts do you base your assertions?

7. List the following cross sections in their order of torsional strength. All of the sections have the same area, and are of the same material.

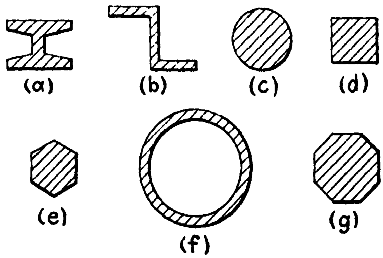


FIG. 155A.

8. *a.* If you were going to design a machine operated by a pedal, similar to the one shown in Fig. 154, what shape of cross section would you use on the main torsion rod?

b. Why not use a square-shaped cross section of the same area?

UNIT 12. Applications of Torsion

There are very many cases in the shops and in everyday life where torsion is involved. Find at least five cases, other than those mentioned in this unit, and discuss them in detail. Make a sketch of each case.

UNIT 13. Shear

The term *shear* is very common in the regular routine of living. In the shops, you hear of shear pins, and the shearing off of rivets, and the shearing cutters of various machines. In the home, the most common illustration of shearing is the scissors, or the shears, as they are oftentimes called. When paper is cut it is sheared. These are only a few of the many illustrations of shear.

Since you are going to study shear more in detail, you must have a definition of the word, not a technical definition, but one in regular, everyday English. The following is such a definition.

> **Definition:** *Shearing stresses* are set up in a material, when two forces in closely adjacent, parallel planes act like a pair of scissors, tending to separate the material between them.

With regard to the definition of shear, examine a pair of scissors, and note that as the cutting edges of the scissors approach each other, they are in planes that are parallel and closely adjacent.

EXPERIMENT

In the experiment which you are to do now, you will investigate and determine the factors which control shearing stresses. The following sketch is that of the apparatus you will use. Note that the material to be tested is placed in the machine by adjusting the shear handle to the position where the holes in both plates line up, and then sliding

the specimen through to the position shown in the figure. In cases where specimens of different diameters are tested, choose the holes in the two plates which are more nearly equal to the size of the specimen.

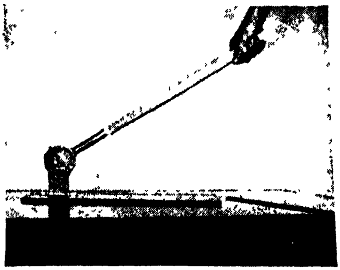


FIG. 156.

Try the amount of force needed on the lever handle to shear off a piece of ⅛-in.-diameter steel rod. Compare this with the amount of force necessary to shear off:

a. A piece of brass rod of the same diameter.

b. A piece of tinsmith's solder of the same diameter.

c. A piece of wood dowel of the same diameter.

(NOTE: Make certain before you begin your test that there is nothing between the two shear plates.)

Record in the data table the amount of force required to shear each of the materials. It is suggested that the following terms be used to denote comparative amounts of shear: "The most," "more," "even more," "even less," "the least," "couldn't shear," "all I could pull," "the easiest," etc. Hook a spring scale in the hole at the end of the handle and check yourself by getting comparative scale readings.

The following data table is the type that you should use for recording the results of your test.

DATA TABLE

Case No.	Material	Diameter of specimen	Amount of force needed to shear	Ability to withstand shear
1				
2				
3				
4				

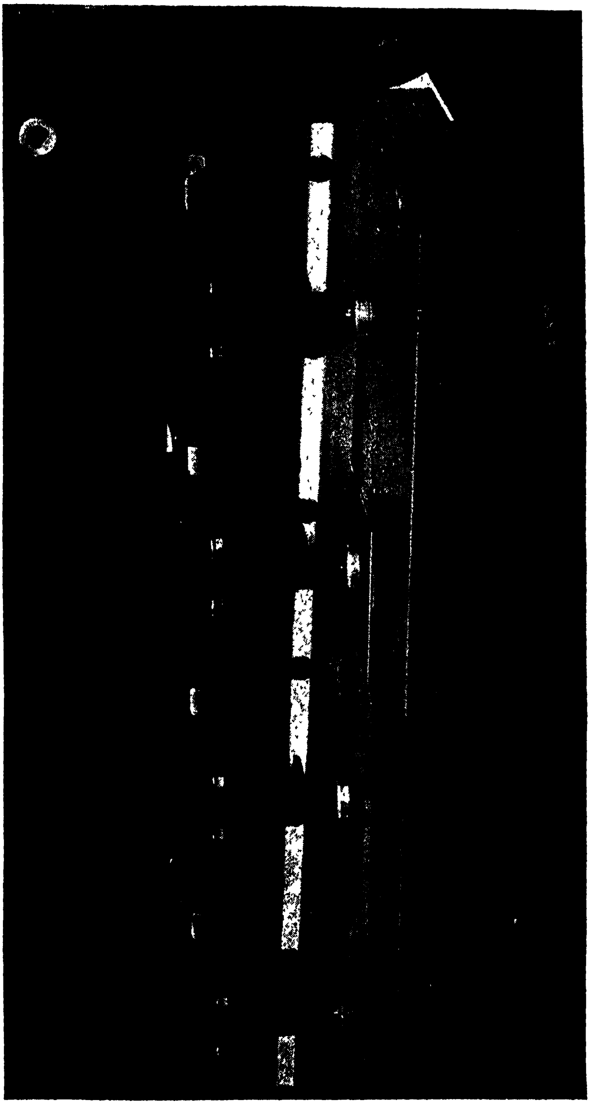
FIG. 157.

After the data table has been filled in completely, study your results carefully. Then answer the following questions:

1. Did you feel any difference in the individual amounts of force necessary to shear each of the materials?
2. Would a difference in the forces necessary to shear indicate any difference in the ability of the material to withstand shearing stresses?
3. Do the facts stated in the last column of your data table agree with your answer to the previous question?

General Conclusion: As your conclusion, make a general statement relative to the behavior of different materials subjected to shearing stresses.

Your next job is to try to determine the factors that control the ability of materials to resist shearing action. Following is a list of a few items that might be considered as control factors. Experiment with each individual item, and record your observations in separate data tables. Add to the list any other control factors that you care to.



Mechanical shear. This shear will cut ½-in. steel plates 10 ft. long. It runs 40 strokes per minute. (*Cincinnati Shaper Company.*)

Item 1. The cross-sectional area of the test specimen.

Using pieces of machine steel whose diameters are $\frac{1}{16}$ in., $\frac{1}{8}$ in., $\frac{3}{16}$ in., and $\frac{1}{4}$ in., make tests to determine the amount of force required to shear off stock of such diameters. Record all data in the table, and in the usual manner.

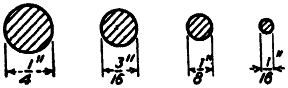


FIG. 158*a*.

Item 2. The spacing between the cutting edges.

In order to separate the cutting edges of the shear, U-shaped washers have been provided in the following thicknesses: $\frac{1}{64}$ in., $\frac{1}{32}$ in., $\frac{3}{64}$ in., $\frac{1}{16}$ in., $\frac{1}{8}$ in. These washers may be slipped in between the two shear plates for spacing. Using a $\frac{1}{8}$-in.-diameter steel rod, try shearing off stock when the cutting edges are set apart at the distances designated by the side sketches. Record all data in a data table in the usual manner.

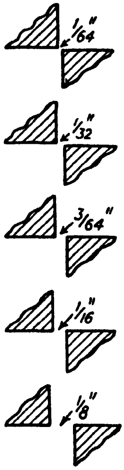


FIG. 158*b*.

Item 3. Etc.

Add as many more items as you like to the list of probable control factors. Make individual tests for each item; then answer the same questions for each of the items individually, making a complete statement in answer to each.

4. Did you observe any difference in the ability of each to resist the shearing stresses in the several cases of the factor in question?

5. Can you say, then, that the factor under consideration affected the ability of the material to withstand the shearing stresses?

Control Factor: Make a statement, now, telling whether or not the factor in question is a control factor of shear.

The shape of the cross section of a material under a shearing stress presents exactly the same resistance to a shearing action, whether it be in the form of a square, or a rectangle, or a circle or any other shape, providing that the cross-sectional area remains constant. In other words, two pieces of the same grade of material with the same cross-sectional area, but having shapes as shown in the following figures, will present exactly the same resistance to a shearing stress, provided that both shear plates operate in directions exactly opposite to each other.

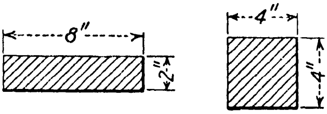


FIG. 159.

SUMMARY

Copy the following statements on your own paper, filling in the words that make the statements true:

8. The resistance that a material offers to a shearing stress may be increased by .... its cross-sectional area.
9. Separating the cutting edges of the shear ... the ability of the material to withstand shearing stresses.
10. Changing the shape of the cross section of a material subjected to shearing stresses .... its ability to withstand the stresses.

UNIT 14. Illustrations of Shear

1. Explain how the principle that you studied in your experiment on shearing stresses applies to the following cases, illustrated by Fig. 160:
   a. A riveted joint being pulled in the directions as shown
   b. Stripping the threads off a screw or nut.
   c. A key on a shaft holding a cam.
   d. Punch press in action.

   Tell in detail how and where shear occurs ultimately in each case. Tell also how you would remedy cases *a*, *b* and *c*, should serious shearing occur.

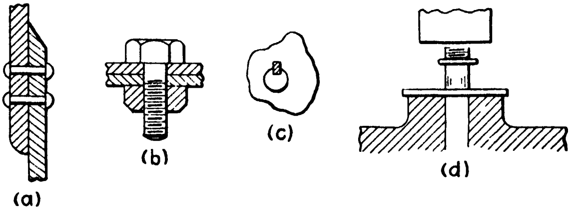


FIG. 160

2. *a*. The similar couplings, used in a machine shop, are jointed together as shown, one with a pin passing the entire way through the driving shaft and the other with a pin that goes only one half of the way into the driving shaft. Which shaft is better equipped to stand heavy overloads?
   b. To which control factor do you tie up your answer?

FIG. 161.

3. Would it be more advisable to use a steel or a lead key in a shaft that was the main power drive shaft for a shop? Why? Explain your answer in terms of your experiment on shearing.
4. Compare the amounts of force that it would require to shear off the following kinds of materials having the

cross sections as named. Arrange them in the order of shearing difficulty from the easiest to the hardest. If you think that two of the materials would require the same force, include them in the same bracket number.

1. Hardened tool steel, 2 in. × 2 in.
2. Hardened tool steel, ½ in. × 6 in.
3. Soft solder, ¼ in. × 8 in.
4. Brass, 2 in. × 1 in.
5. Soft steel, ½ in. × 4 in.
6. Lead, 1 in. × 1 in.
7. Soft steel, 1 in. × 3 in.
8. Brass, 2 in. × 1½ in.

5. A man designed a punch press to punch holes in a steel plate as shown below. The holes were ¾ in. in diameter, and the stock was ⅜ in. thick. In designing the machine, however, the man allowed the punch to be exactly ⅝ in. in diameter, and the die with which the punch worked to be ⅞ in. in diameter. Explain in terms of your experiment your opinion of the machine designer's knowledge of shear.

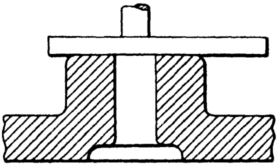


Fig. 162.

6. List the following specimens in their order of shearing difficulty. They are all made of the same material, and have identical cross-sectional areas.

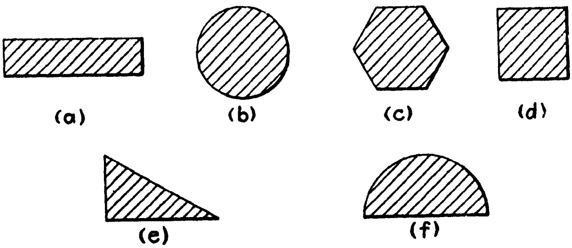


Fig. 163.

7. A steel plate ¾ in. thick requires 30,000 lb. of force to punch a certain square hole through it. How much force would it require to punch the same hole through a piece of ¼-in. steel plate?

UNIT 15. Applications of Shear

Name and explain in detail at least two places, not mentioned previously, in an automobile, wherein shearing stresses are constantly in action. Make sketches wherever necessary to *illustrate* your explanation. Bring into class at least three cases where shearing occurs in your trade, or in your everyday life. Make a sketch of each case and discuss it in detail.

UNIT 16. Shock Load

Suddenly applied loads producing shocks and jars are often encountered in the operation of machines. Such machines as punch presses, internal-combustion engines, riveting hammers, etc., are vivid illustrations of loads being applied as shocks.

Definition: The shock experienced when a load in motion has its direction abruptly changed, or

is brought abruptly to a stop or to a greatly reduced speed, is called *shock load.*

Shock load may be applied to any of the stresses that you have studied thus far, it is not confined to any one stress. In cracking a hickory nut between two stones, shock load is applied to compression. When screwing up a piece of brass pipe with a quick jerk on the wrench, shock load is being applied to torsion. A punch press uses the principle of shock load as applied to shear when it punches holes through heavy stock. You see, then, that a shock load may occur wherever there is a load in motion. For this experiment, however, you will experiment with only one type of shock load, that of shock load applied to compression. Remember, the identical principles hold true in all other cases, regardless of the nature of the stress.

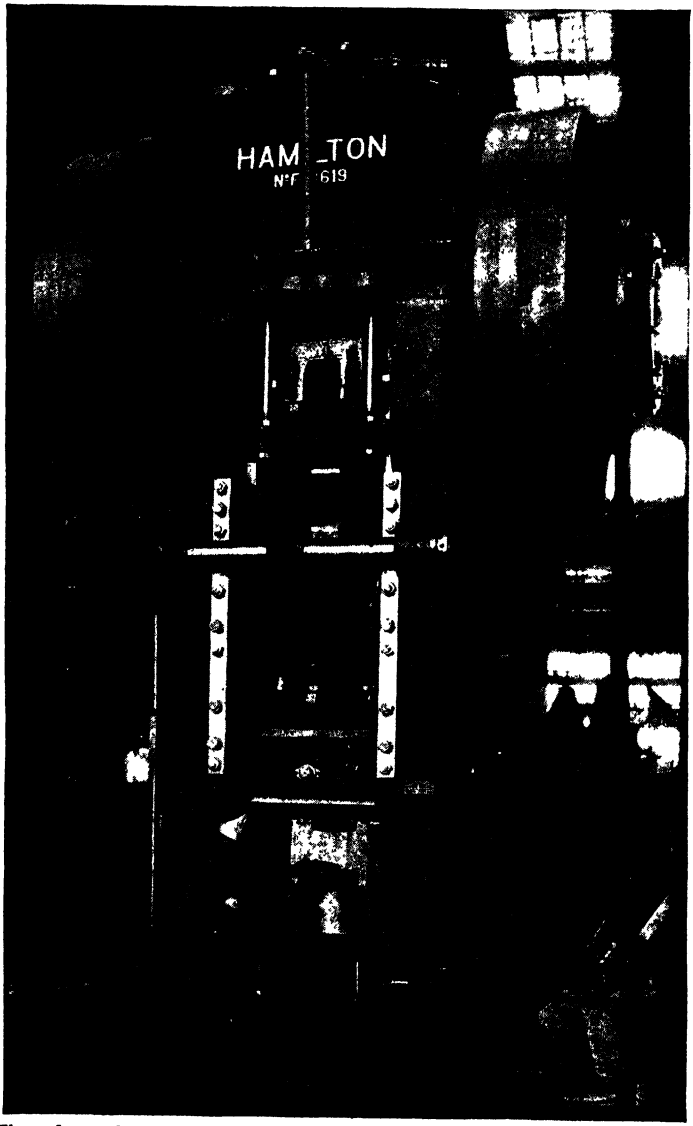
First, you will prove to yourself the effectiveness of a shock load; then you will proceed to investigate the factors that control it.

Fig. 164.

EXPERIMENT

The apparatus you will use in your first test consists of a rope, a weight and a 50-lb. scale, hung from a steel girder as shown in Fig. 164.

Hang a very small weight (about 2½ lb.) on the rope end. Note the scale reading. Now raise the weight about 6 in.



The drop hammer utilizes shock load. (*American Machinist.*)

with your hand, and after making certain that the rope is securely fastened to both the weight and the scale, drop the load suddenly. Note the scale reading when the load is brought to an abrupt stop at the end of the rope.

Then answer the following questions, making a complete statement in answer to each:

1. Was there a great difference in the two scale readings?
2. From the foregoing definition, what name would you give to the greater of the two scale readings?

General Conclusion: As your general conclusion, make a statement on the effect of bringing a load in motion to an abrupt stop.

Since you now know the cause of shock load, your next job will be to investigate the factors that control it. Following are a few items that you might use as starters in your determination of the control factors:

Item 1. The magnitude of the load.

Item 2. The speed at which the load is traveling at the time of the blow or the abrupt change of direction.

Item 3. Etc.

Fig. 165.

The apparatus to be used in determining the control factors consists of a hollow column, about 3 ft. high, as illustrated by Fig. 165.

The specimens to be tested are placed centrally inside the hollow column, and are there subjected to shock loads caused by dropping weights within the column.

In testing to determine whether Item 1 is a control factor or not, use lead shot as the material to work on. First, with a small weight held 24 in. above the specimen, place a single lead shot at the midpoint of the anvil. The anvil is the steel plate at the base of the hollow column. Then pull the release catch, and observe what happens when the load hits bottom. Examine the lead shot carefully. Warning! Make sure that all other release catches are pulled back out of the way, before allowing the load to drop!

Repeat the entire procedure using the next largest weight and a new lead shot; finally observe what happens when the largest weight is used. Record all your observations in a data table similar to the one following. Make certain that each of the three weights is dropped from the same height.

DATA TABLE
Different Loads

Case No.	Magnitude of the load	Amount that lead shot was crushed	Amount of shock load delivered
1			
2			
3			

FIG. 166.

Study the results shown in the data table, and answer the following questions:

3. Did you notice any difference in the distortion of the lead shot due to the variation of the load?

4. Would a difference in the distortion of the lead shot indicate that different amounts of shock load had been delivered to the shot?

Control Factor: Make a statement now telling whether or not the magnitude of the load is a control factor and, if so, how a variation in the load affects shock load.

Now arrange the apparatus in preparation for investigating Item 2. In order to test and determine whether the velocity or speed of the load at the impact is a control factor, three release catches have been provided at points 6 in., 12 in. and 24 in. above the anvil respectively. Use the large weight only, and allow it to fall on three different specimens of lead shot. In order to produce different velocities so that a comparison of results may be made, the load is dropped from different heights above the anvil. In other words, if the block of steel is dropped from the 6-in. height, its velocity at the bottom of the chute will be much less than when it is dropped from the 24-in. height. Using the three heights mentioned, carry on your experiment, and record your observations in a data table similar to the one shown by the following figure.

Data Table
Different Velocities

Case No.	Velocity of the load	Amount that lead shot was crushed	Amount of shock load delivered
1			
2			
3			

Fig. 167.

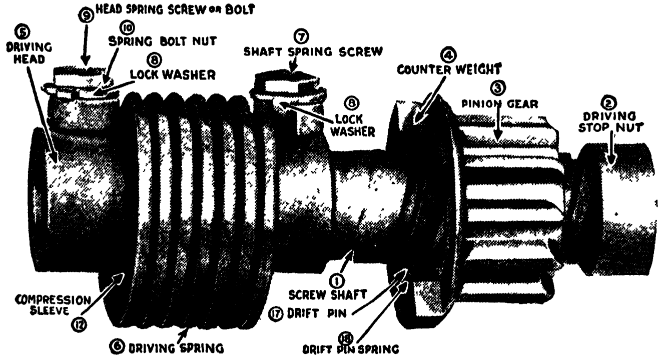
Examine the three specimens of shot carefully. Then answer the following questions with a complete statement:

5. Did you notice any difference in the distortion suffered by the lead shot, due to the variation in velocity of the load?
6. Would a difference in the distortion of the lead shot indicate that the shock load delivered to the shot had been varied?

Control Factor: Make a statement, now, telling whether or not the velocity at which the load is moving at the moment of impact is a control factor and, if so, how a variation in the velocity affects the shock load.

7. Suppose the load does not fall, but is slid along a flat plate, what will be the control factors of the shock load in this case?

Experiment with as many more items as you wish to consider in your determination of the control factors. If you need additional equipment, see your instructor. Make a data table for each new item that you test.



Bendix drive. Illustrates one mechanical method of absorbing shock load. (*Eclipse Machine Company.*)

SUMMARY

Copy the following statements on your own paper, and fill in the words that make the statements true:

8. If a load in motion has a greater velocity than a similar second load, the first load will deliver the .... shock load.
9. Increasing the magnitude of the object delivering the load, while keeping velocity constant . ... the ability of the object to deliver shock load.

UNIT 17. Illustrations of Shock Load

1. Why are pile drivers made with such high columns? To which control factor does this fact tie up?
2. *a.* In battering a door down with a log for a ram, why is it necessary to get a running start?
   b. To which control factor does this fact tie up?
3. *a.* In punching holes in many sheets of paper at the same time, why is it necessary to start the punching stroke with your hand a foot or more above the lever of the punch and then jam down as hard as you can to punch clear through the paper?
   b. To which control factor does this fact tie up?
4. *a.* Why is a harder blow struck when a car hits an object at 50 mi. per hour rather than 25 mi. an hour?
   b. To which control factor does this fact tie up?
5. *a.* Do you get more or less shock load by swinging a 15-lb. sledge hammer through the same distance than by swinging a 12-lb. hammer, if you double the speed of swing of the 12-lb. hammer?
   b. To which control factor does this fact tie up?
6. *a.* Why is it more difficult to bring a 10-ft. cast-iron flywheel to a stop, than a 2-ft. flywheel?
   b. To which control factor does this fact tie up?

7. Did you ever notice a baseball player's hands, when he catches a fast throw? Why does he allow his arms to swing in the direction that the ball is traveling?
8. When you break a piece of string with a sudden snap of your hands, this is shock load applied to what stress?
9. When you twist off a bolt head with a sudden jerk on a wrench handle, this is shock load applied to what stress?

UNIT 18. Applications of Shock Load

Find at least one application in your trade or daily life wherein shock load is applied to the following stresses:

1. Tension	3. Torsion
2. Compression	4. Shear

Tell in detail how each case functions, and if possible make a sketch of the setup.

Also find at least three other cases of shock load of your own choice. Make a sketch of, and report on, each case in detail.

UNIT 19. Inertia, Momentum, Velocity, Acceleration, Centrifugal Force, Gyroscopic Action, Gravitation

Instead of studying each of the subjects named in the above title individually as separate units, you are

going to meet all of them in this unit, and study them purely as informational subjects. There are to be no experiments performed. Reading references will be given you, following each new subject. The textbooks named as references, you will find in your instructor's bookcase.

INERTIA

Definition: *Inertia* is the tendency of a substance at rest to resist motion, and the tendency of a substance in motion to continue in motion.

As a practical illustration of the effectiveness of inertia, have you ever tried to drive a nail into a small piece of wood that you were holding in your hand, and then have you noticed the ease with which the nail may be driven by holding a heavy object on the other side of the piece while nailing? This is caused by the tendency of the heavy object in back of the piece to remain at rest and resist motion. This tendency is called *inertia*.

As another instance of inertia, try to picture an enormous steel ball resting on a flat surface. Now, if you try to start the ball rolling with a sudden jolt and find you cannot, you have the inertia of the ball to contend with. Then, after pushing against the ball with a continuous force, and succeeding in getting it to roll at an appreciable speed, if you decide to stop the ball or retard its motion somewhat, you find that it is almost impossible because the ball has a tendency to keep right on rolling. This tendency is another phase of inertia.

In order that you may study the subject of inertia more completely read:

Essentials of Physics by Hoadley, p. 17.
Elementary Practical Mechanics by Jameson, p. 7.

MOMENTUM

Momentum and inertia are very closely linked together.

> **Definition:** *Momentum* is the measure of the inertia of a body in motion, and mathematically is the product of the mass of the body and the square of the speed at which it is moving.

The momentum of some objects is enormous. The 100-car freight trains that travel at the rate of 40 or 50 miles per hour require an enormous force to overcome their momentum and bring them to a stop. An airplane mechanic uses the principles of inertia and momentum when he uses an "inertia starter." We depend on the momentum of a hammer to drive a nail for us and the momentum of a flywheel and crankshaft in an automobile to keep the engine turning; in short, we depend on momentum in very many instances in our regular everyday life in order to keep our commercial and industrial machines and appliances in continuous motion.

For a more complete discussion of momentum and its measurement, it is suggested that you read:

Elementary Practical Mechanics by Jameson, pp. 176–180.
Mechanics by Smith, p. 38.

VELOCITY AND ACCELERATION

When an automobile is traveling at 50 miles per hour, we speak commonly of its speed being its velocity. When an airplane is traveling through the air at a high speed, its speed is termed velocity also. Wind speed is usually spoken of in terms of velocity.

Definition: *Velocity* is the speed with which an object travels in relation to some set standard.

The velocity of an object may be stated in any of several kinds of measuring units, such as feet per minute, miles per hour, kilometers per hour, meters per second, etc.

The velocity of any one object is not always the same, however; it changes with the condition. When the velocity of an object is increasing it is said of that object that the velocity is accelerating, but when the velocity is decreasing, it is said that the velocity is negatively accelerating. In order to have acceleration, a force must be applied to the moving body. Thus, when a baseball is dropped from a tower, it goes faster and faster; it has regular or uniform acceleration. When, however, it is thrown upward, it goes more and more slowly; it has negative acceleration.

Definition: *Acceleration* is the rate at which the velocity of a body is increased or decreased.

The units of measurement for acceleration are feet per second per second, meters per second per second, etc. In other words, if an automobile increases its velocity at the rate of 5 ft. per second in *every* second,

its rate of acceleration is stated as 5 ft. per second per second. This type of acceleration is termed "uniform acceleration."

The following books contain an excellent store of additional information on velocity and acceleration. It is suggested that you read the references carefully.

Mechanics by Smith, pp. 35–38.
Practical Physics by Black and Davis, Chap. VII.
Essentials of Physics by Hoadley, pp. 36–37.
Elementary Practical Mechanics by Jameson, pp. 13, 105.

From the foregoing explanations, you should be able to visualize the applications of those principles to practice. For instance, when you stand up in a street car that is about to start, the jerk of starting throws you off balance backwards due to your own "inertia" or tendency to resist motion. At the same time, the street car is trying to overcome its own "inertia" by speeding up or "accelerating." The "acceleration" goes on for a while at the rate of several feet per second per second, until the car has attained the desired "velocity" of a certain number of miles per hour. Upon approaching the next regular stopping place the brakes are put on, whereupon you are again thrown off balance due to your tendency to keep right on going, or your "momentum." (Remember, your "momentum" is the measure of your "inertia.") This example shows clearly the real everyday-life applications of these scientific principles.

CENTRIFUGAL FORCE

When an automobile, traveling at high speed, takes a curve too sharply, the passengers find themselves

crowded up against the cushions nearest the outside of the curve. This tendency is caused by the factor known as centrifugal force.

Definition: The *centrifugal* tendency is the tendency of an object traveling in a circle or the arc of a circle, to leave the circular path and travel in a straight line, tangent to the circular path of travel. *Centrifugal force* is the force that the object exerts in trying to leave the path.

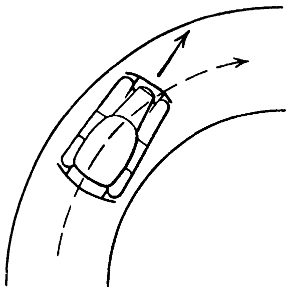


Fig. 168.

Another illustration of the centrifugal tendency is that of an athlete swinging a big hammer about his head in preparation for a throw.

You will notice that so long as he holds on to the hammer, it will continue to follow a path as shown by the dotted line in Fig. 169. If, however, he releases the hammer, it will immediately leave the path of former travel at a tangent, as shown by the solid line.

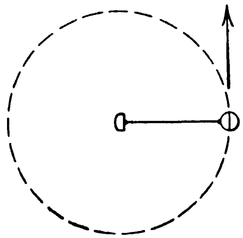


Fig. 169.

For a more complete treatise on the centrifugal force and its measurement and applications, study the following references:

Mechanics by Smith, pp. 208–210.
Essentials of Physics by Hoadley, pp. 63–65.
Elementary Mechanics by Jameson, p. 158.

Practical Physics by Black and Davis, pp. 176–179.
Power Plant Machinery by James and Dole, p. 78, Art. 60.

GYROSCOPIC ACTION

Definition: *Gyroscopic action* is the tendency of a rotating body to resist any effort that would change its plane of rotation or the direction of its axis.

In 1933, three enormous gyroscopic flywheels were installed in the Italian ocean liner *Conte di Savoia* to eliminate the tendency of the boat to roll at times when the ocean was rough. Following is the report of the occasion as reported by the Hartford Connecticut *Courant* on January 2, 1933:

"The New Italian liner *Conte di Savoia* displaces 48,000 tons. Yet three spinning tops or flywheels weighing 660 tons, or a little less than 1.5 per cent of her total displacement, control her perfectly. Moreover, they do this with an expenditure of not more than 1900 horsepower, or 1.5 per cent of the horsepower of the main engines.

"These seasickness-preventing stabilizers are like ordinary tops in principle, except that they are mounted in bearings, which are fastened to the ship's frame. As long as it spins fast enough any top stands upright. Try to push it over and it wabbles as it slowly recovers itself. That is, its vertical axis describes a wide circle which grows smaller and smaller until the top stands upright again. The wabble is called the top's precession.

THE TOP PRINCIPLE APPLIED

"The top stands up because, like every rapidly rotating body, it resists any force that tends to disturb its plane of

rotation. Mount a top or gyroscope on a vehicle with only two wheels arranged in tandem. The vehicle will stand up so long as the top is spinning. Push the vehicle over and the spinning wheel will bring it back to an upright position.

"As soon as the *Conte Di Savoia* starts to roll, the plane of rotation of the gyroscopes is disturbed. Their vertical axes tip forward, or precess. The effect is to counteract the increase in buoyancy on the side of the approaching wave. It is just as if a weight were shifted from one side of the ship to the other—just enough weight to offset the roll. However, in this case one nicely adjusted force is opposed to another force.

"It takes time for a big gyroscope to feel the wave and start to tilt. Moreover, when it has started to tilt its inertia may keep it moving. This is one reason why efforts to use the gyroscope in Germany before the war were not a complete success. The late Elmer Sperry hit on the ingenious idea of using a small control gyroscope to tell the big gyro what to do when, in other words, the control gyroscope, being small, responds to the beginning of a roll almost instantly. Through an automatically started electric precession motor the response is communicated to the big gyroscope. Hence the big gyro begins to precess sooner than it would if it had first to overcome its own sluggishness.

"The reason why three gyroscopes with three smaller controls can steady the mighty *Conte di Savoia* is to be found in the very nature of wave action. One wave does not make a ship roll. It takes a succession of waves to do so. Hence, if the first sign of a roll can be checked there is no cumulative effect to overcome. Instead of rocking from side to side the huge ship rises and falls slowly while the waves pass under her.

"It was no revolutionary proceeding to equip the *Conte di Savoia* with gyroscopes. Some forty vessels, most of them yachts owned by men who would never go to sea if the price of ocean luxury were illness produced by rolling, have gyrostabilizers. The *Conte di Savoia* is merely the first passenger liner to be provided with stabilizers of the gyroscopic type."

As a reference, use:

Essentials of Physics by Hoadley, pp. 65–66.

GRAVITATION

Definition: *Gravitation* is the attraction that one body has for another.

All materials are attracted to the earth by gravity. The earth's pull on all substances acts in a way similar to the attraction of a piece of steel to a magnet. In a similar way that the attraction for the magnet weakens with the increase in the distance between the steel and the magnet, we find that gravity varies as the substance is taken farther and farther away from the center of the earth. A piece of metal weighing one pound at sea level will weigh somewhat less at the top of Mt. Washington, and still less at an altitude of fifty thousand feet. As a point of information, it has been estimated that at a point approximately six-sevenths of the distance from the earth to the moon gravity apparently ceases for the earth and the gravitation toward the moon begins. This means that at a point six-sevenths of the way between the earth and the moon, and in the same line, there is no gravity, and

all things have no weight; for example, 100 lb. of steel would weigh as much as 10,000 lb.; namely, 0.

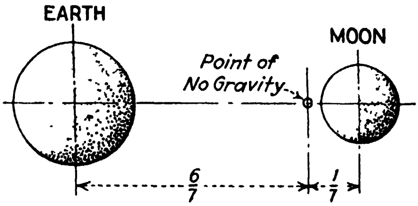


Fig. 170.

Therefore, gravity as you must think of it, is the pull that exists between the earth and a substance, the amount of the substance determining the amount of its attraction for the earth.

For additional information on gravitation see:

Essentials of Physics by Hoadley, pp. 80–81.
Mechanics by Smith, Chap. IV.
Practical Physics by Black and Davis, pp. 182–184.

UNIT 20. Illustrations and Applications of Gravity, Acceleration, Momentum, Inertia, etc.

1. Why does an automobile continue to move for awhile after the ignition has been shut off? To what fact can you tie up your answer?
2. To what fact can you attribute the information that small grinding wheels may be driven at a greater number of revolutions per minute than larger wheels?
3. If a moving train is suddenly stopped by emergency brakes in which direction are the passengers thrown?

Explain in terms of the facts that you studied in this unit.

4. Why is an indoor running track banked at the turns? Explain in detail.
5. When you swing a full pail of water in a circle about your head, why is it that the water does not empty itself from the pail?
6. A baseball is thrown directly upward in the air and continues to travel upward for 4 sec. How long will it take the ball to return to the thrower's hands after it has ceased to move upward?
7. Would a 400-ton train have more or less momentum than a 410-ton train if both were traveling at the same rate of speed? Explain why.
8. In a previous unit, you studied shock load. What does the amount of shock delivered at any one time depend upon? Explain in terms of the facts that you studied in this unit.
9. Explain in terms of velocity and acceleration everything that occurs when you step into an automobile, start it, drive it until you attain a speed of 50 mi. per hour, put the brakes on suddenly and come to a stop.
10. Could a cream separator be used to separate a solution of soluble oil and water? Explain in detail your point of view. (Soluble oil and water make up that milky-white cutting compound used in many machine shops.)
11. Find at least ten other cases of the several principles involved in this unit, in your shop or home life. Make a sketch of each case if possible and discuss it in detail. Find at least one case for each of the principles involved.

INDEX